



Stock assessment of stout whiting (*Sillago robusta*) in eastern Australia

2021

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Summary

Stout whiting are a relatively short-lived species and grow to a maximum size at 22 cm fork length at about eight years of age. Most of the commercial catch comprises one to three-year-old fish (12–17 cm fork length).

Sexual maturity is reached at one to two years of age. Spawning activity peaks between August and October. Adult stout whiting often form relatively dense schools on sandy substrates and trawling activities are confined to these areas. It is suspected that schooling aggregations most often form at dawn and dusk. Juvenile fish of less than one year of age and 10 cm fork length occur in shallow waters adjacent to ocean surf beaches. Stout whiting move offshore into depths greater than 30 m at about 1 year old (10–13 cm fork length).

Stout whiting form a single biological stock across Queensland and New South Wales waters. Until 2017 the stout whiting fishery in southern Queensland was restricted to offshore waters south of Sandy Cape in depths ranging between 20 and 50 fathoms (36–90 m). As part of a management trial a permit was issued between 2017 and 2020 that allowed stout whiting operators to fish within 20 fathoms. The distribution of stout whiting in northern New South Wales waters overlap with the temperate eastern school whiting (*Sillago flindersi*), also known as the red spot whiting. Catches south of Newcastle (33 °S) in New South Wales are comprised almost exclusively of eastern school whiting.

This assessment builds on previous work that estimated the stock was at just below 40% of unfished biomass in 2004 and marginally above the biomass that would produce maximum sustainable yield in 2014. This stock assessment includes updates to the input data and methods.

This stock assessment used an age structured population model with a yearly time step defined to be the same as financial year, so 1 July 2019—30 June 2020 was the 2020 fishing year. The model considered two subpopulations defined by the Queensland and New South Wales commercial fishing sectors.

The model incorporated data spanning the period from 1945 to 2020 including commercial harvest (1945–2020), commercial catch rates (1991–2020) and age-length monitoring (1991–2015). Discarded bycatch from the Queensland prawn trawl fishery and the New South Wales Ocean Trawl fishery were included.

The majority of the total harvest can be attributed to Queensland (Figure 1). The harvest estimates indicated that over 2000 tonnes (t) of stout whiting were landed annually by the Queensland commercial stout whiting fishing sector in the late 1990s. In recent years the estimated Queensland commercial harvest from the stout whiting fishing sector reduced to just over 1000 t annually, which is close to the total allowable commercial catch. Bycatch estimates from the Queensland prawn trawl sector are for a similar tonnage. Over the last five years, from 2016 to 2020, the Queensland commercial harvest from the stout whiting fishing sector averaged 1063 t per year, the New South Wales stout whiting harvest averaged 176 t per year and the Queensland stout whiting commercial harvest was 46% of the total harvest with bycatch.

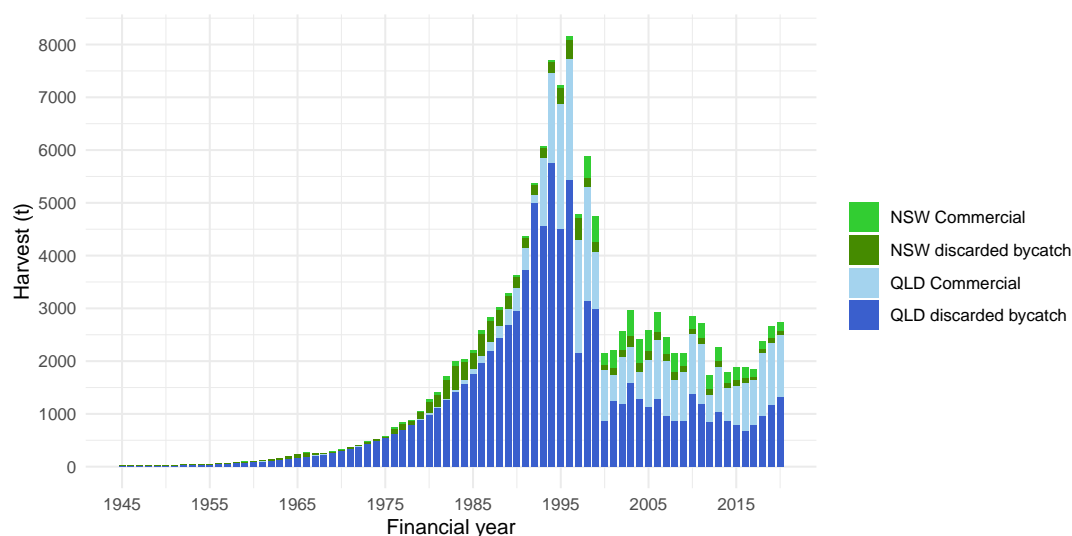


Figure 1: Annual estimated harvest from commercial sectors between 1945 and 2020

Commercial catch rates were standardised to estimate an index of stout whiting abundance through time (Figure 2 and Figure 3). The unit of standardisation was kilograms of stout whiting per “operation-day”, defined to be a single day of fishing by a primary vessel. Year, seasonality, region (defined by spatial grid mappings), vessel, hours fished, water depth, lunar, fishing experience, wind speed and direction, the use of sonar and combinations of these were included explanatory terms.

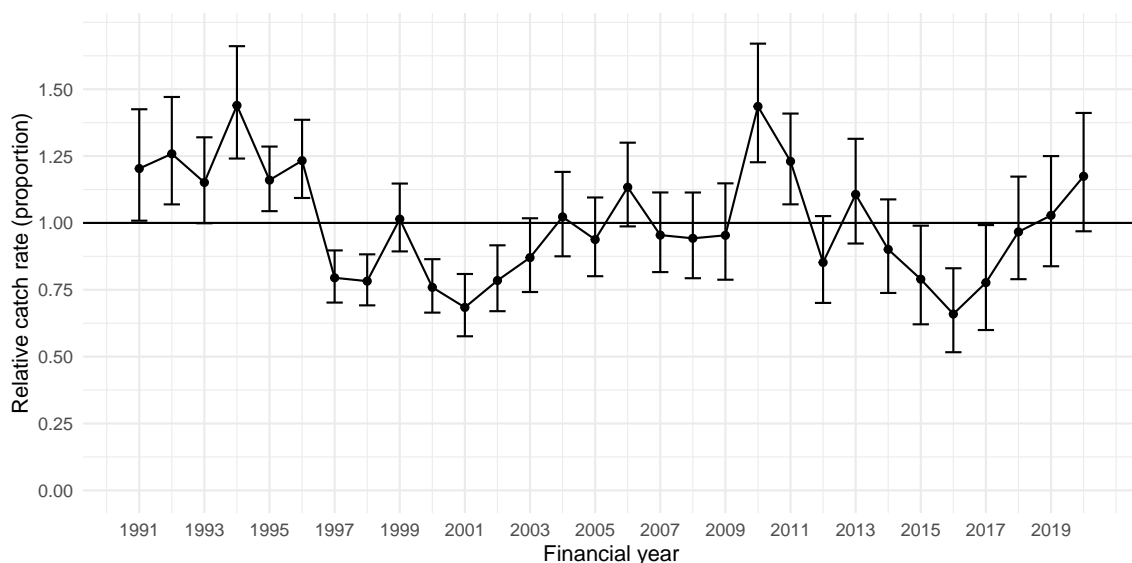


Figure 2: Annual relative standardised catch rates and 95% confidence interval for the Queensland commercial stout whiting fishery from January 1991 to June 2020

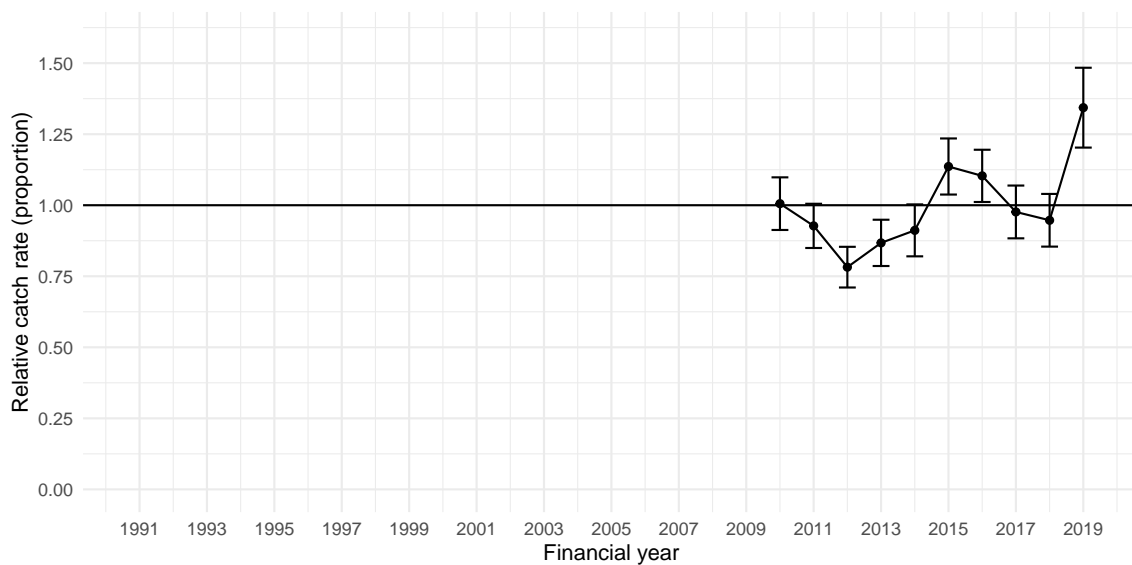


Figure 3: Annual relative standardised catch rates and 95% confidence interval for the New South Wales commercial stout whiting fishery from July 2009 to June 2019

Model results suggested that biomass declined between 1945 and 2000 to 27% unfished biomass. In 2020, the stock level was estimated to be 42% unfished biomass (Figure 4).

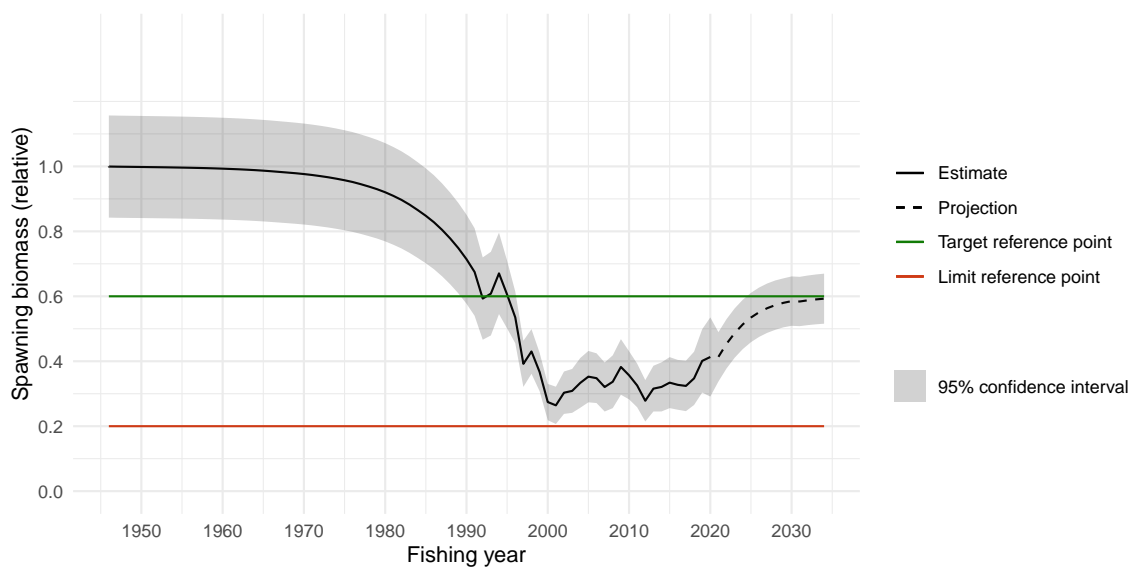


Figure 4: Predicted spawning biomass trajectory relative to unfished from 1945 to 2020 financial year

Maximum sustainable yield was estimated at 3259 t per year and the harvest consistent with a biomass ratio of 60% (a proxy for maximum economic harvest) was estimated at 2897 t (all sectors and waters, including bycatch from the Queensland prawn trawl fishery).

The recommended biological harvest in the 2021 fishing year is 2018 t for all sectors and waters to achieve a longer-term target of 60% unfished biomass with a buffer of 0.87 by 2040.

Table 1: Current and target indicators for stout whiting in all sectors and waters

Parameter	Estimate
2020 spawning biomass (relative to unfished)	42%
Maximum sustainable yield	3259 t
Maximum sustainable yield biomass (relative to unfished)	42%
2020 harvest	2668 t
Equilibrium 60% biomass harvest	2897 t
2021 harvest to achieve 60% biomass	2018 t

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Glossary

AUD	Australian dollar
B_{MSY}	Biomass at maximum sustainable yield
BRD	Bycatch reduction device
CI	Confidence interval
fishing year	For stout whiting, fishing year is defined to be the same as financial year, so 1 July 2019–30 June 2020 is the 2020 fishing year
fleet	A Stock Synthesis modelling term used to distinguish types of fishing activity: typically a fleet will have a unique curve that characterises the likelihood that fish of various sizes (or ages) will be caught by the fishing gear, or observed by the survey
FRDC	Fisheries Research and Development Corporation
ITCAL	Interim total commercial access level to transition to a total allowable effort quota in 2024
MSY	Maximum sustainable yield—the maximum level at which the species can be routinely exploited without long-term depletion
NSW	New South Wales
Operation-day	A single day of fishing by a primary vessel, with year, month, stratum, number of dories and number of crew and combinations of these as explanatory terms
OTF	Ocean Trawl Fishery
QLD	Queensland
RBC	Recommended biological catch—the estimated total annual catch that can be taken by fishing, while achieving the management objectives for the fishery
SB	Spawning biomass - the number of eggs (spawning egg production)
SB_0	Unfished spawning biomass
SB_{2020}	Spawning biomass in 2020
SFC	Southern Fisheries Centre
SS	Stock Synthesis
TACC	Total allowable commercial catch
t	Tonnes
T_1	Queensland prawn trawl fishery
T_4	Queensland stout whiting fishery

1 Introduction

Stout whiting (*Sillago robusta*) are endemic to Australia, occurring between Shark Bay and Fremantle in Western Australia and between Bustard Head in Queensland and northern New South Wales along the east coast. The stout whiting population along Australia's east coast constitutes a single stock unit (Ovenden et al. 1999). Its distribution overlaps with the northern distribution of the eastern school whiting (*Sillago flindersi*), also known as the red spot whiting. Catches south of Newcastle (33 °S) are comprised almost exclusively of eastern school whiting. This stock assessment focuses on the commercial stout whiting fishery operating along Australia's east coast.

Stout whiting are a relatively short-lived species and grow to a maximum size of 22 cm fork length (FL) at about eight years of age (Butcher et al. 2003). Most of the commercial catch comprises 1- and 3-year-old fish (12–17 cm FL) (O'Neill et al. 2003; Gray et al. 2017). Sexual maturity is reached at 1–2 years of age. It was thought that the summer months (December–February) represented the major spawning season for stout whiting. However, fisheries biologists have identified that the gonado-somatic index for male and female stout whiting peaks between August and October, which indicates greater spawning activity during those months (O'Neill et al. 2003). Adult stout whiting often form relatively dense schools on sandy substrates and trawling activities are confined to these areas. It is suspected that schooling aggregations most often form at dawn and dusk. Juvenile fish less than one year of age (< 10 cm FL) occur in shallow waters adjacent to ocean surf beaches. Stout whiting are fast growing and move offshore into depths greater than 30 m at about 1 year old (10–13 cm FL).

In Queensland, stout whiting are caught by Danish seine and fish otter-trawl between Sandy Cape and the Queensland–New South Wales border. Otter trawl restrictions include

- maximum total net length (combined head rope, bottom rope and all other rope attached to the net) of 88 m
- maximum sweep length of 128 m each
- minimum mesh size of 38 mm
- maximum vessel length of 20 m
- turtle excluder devices on all otter trawl nets.

Danish seine restrictions include

- maximum total net length (combined head rope, bottom rope and all other rope attached to the net) of 88m
- minimum mesh size of 38mm
- haul ropes must not be longer than 2500 m
- maximum vessel length of 25 m
- no turtle excluder device is required.

The Queensland commercial fishing sector is identified by a T_4 symbol, which allows licence holders to operate in waters between 20 and 50 fathoms between Sandy Cape and the Queensland border to target stout whiting. The fishery is a limited-access fishery with five T_4 licences currently operated by two licence holders (one using Danish seine gear and the other using otter trawl nets) (Appendix B.3.4). Other than the T_4 fishing sector, no other sectors are licensed to retain stout whiting that are caught as

bycatch (Table 1.1). The TACC for Queensland was 1106 t for 2017–2020, and was increased to 1192 t for the 2021 fishing season. The T_4 sector is managed and monitored separately to the trawl-whiting (stout and eastern school whiting) vessels operating in New South Wales. The T_4 sector is also managed separately to the much larger otter-trawl sectors that target eastern king prawns along Australia's east coast, however, this sector is a major source of stout whiting bycatch.

A history of management changes that have influenced the stout whiting fishery in Queensland is given in Table 1.1.

Table 1.1: History of stout whiting management in Queensland

Year	Management change
1981	Stout whiting fishery begins, restricted area between the 20 and 50 fathom contours between Sandy Cape and Caloundra
1998	Introduction of annual TACC of 1400 t
2000	Adjusted annual TACC to 1000 t, stout whiting vessels not allowed to fish during the first southern prawn trawl closure from midday on 20 September to midday on 1 November
2003	Adjusted annual TACC to 800 t
2004	Adjusted annual TACC to 1000 t
2005	Adjusted annual TACC to 1150 t
2006	Adjusted annual TACC to 1200 t
2007	Adjusted annual TACC to 1250 t
2008	Adjusted annual TACC to 1350 t
2009	Adjusted annual TACC to 1450 t, a permit to expand the fishery area south of Caloundra to New South Wales border was issued
2010	Adjusted annual TACC to 1500 t
2012	Adjusted annual TACC to 1400 t, southern fishery area (south of Caloundra to New South Wales border) was legislated in the regulations
2013	Adjusted annual TACC of 1350 t
2014	Adjusted annual TACC to 1150 t
2016	Adjusted annual TACC to 1090 t
2017	Adjusted annual TACC to 1106 t, as part of a management trial a permit was issued between 2017 and 2020 that allowed the stout whiting operators to fish within 20 fathoms and closed the southern fishery area between 20 September and 1 April each year
2020	Permit amended to remove fishing inside 20 fathoms, southern closure remains
2021	Adjusted annual TACC to 1192 t

The Queensland stout whiting harvest landings have an annual gross value of around AUD3 million depending on export market prices, the value of the AUD currency and volume caught.

The reported commercial catches from Queensland have historically far exceeded those taken from commercial New South Wales waters. On average, 80% of the annual commercial catch is taken from Queensland and 20% from New South Wales (Hall 2019). Commercial catch of stout whiting in New South Wales waters is taken almost exclusively (around 94%) by trawl fishing, as a by-product of prawn trawling (Hall 2019). Total catches in New South Wales from non-trawl fisheries, including recreational catches, have been less than 2 t annually. A few fishers within the New South Wales fish trawl sector use Danish seine. The trawl fishery is a share managed fishery, with access to the fishery limited to shareholders. In 2020 there were 43 fishing businesses that reported stout whiting catch in the prawn trawl fishing sector in New South Wales (Appendix B.3.3).

The New South Wales ‘trawl’ whiting (eastern school whiting and stout whiting) TACC was first introduced in the 2019–2020 fishing season (1 May 2019 to 30 April 2020) and was set at 1189 t (Table 1.2). The 2020–21 TACC for trawl whiting is 898.1 t. A trawl whiting harvest strategy is currently being developed for the New South Wales Ocean Trawl Fishery, which will include updated management objectives and reference points for stout whiting. Currently, the fishery is managed according to the objectives outlined in the Fishery Management Strategy for the Ocean Trawl Fishery (New South Wales Department of Primary Industries 2007).

Table 1.2: History of ‘trawl’ whiting (eastern school whiting and stout whiting) management in New South Wales

Year	Management change
1950s	Trawl fishery begins
mid–1980s	Limited entry for offshore prawn sector
1997	Limited entry restricted fishery management regime for all sectors
2006	Share management regime for all sectors north of Barrenjoey Point
2017	Interim total commercial access level (ITCAL) of 14 370 days for the in-shore and offshore prawn sector
2019	TACC of 1189 t for combined stout whiting and eastern school whiting
2020	TACC of 898.1 t for combined stout whiting and eastern school whiting
2021	TACC of 1066 t for combined stout whiting and eastern school whiting

The total value of stout whiting catches in New South Wales in 2018–19 was approximately AUD1 million.

There is cooperation between Queensland and New South Wales on data exchange and science for stout whiting, but there are no formal mechanisms to cooperate on management of the shared stocks or to ensure the two TACCs together are compatible with the long term sustainability of the stock. As both jurisdictions develop harvest strategies, efforts will be made to align targets and ensure common management of this joint stock.

Previous stock assessments for stout whiting were:

- O'Neill et al. (2003) used a surplus production model and a monthly age-structured model for the Queensland part of the stock. Results estimated the ratio of exploitable biomass in 2002 to the exploitable component of the carrying capacity (B_{2002}/K) at 0.19
- O'Neill et al. (2005) used a surplus production model and an annual age-structured model for Queensland and New South Wales. Results estimated TACCs for 21 scenarios that comprised different catch components and natural mortality estimates. The age-structured model predicted exploitable biomass ratios for seven analysis scenarios. The analyses all predicted a declining biomass between 1991 and 2000. The base case scenario biomass was just below 0.4 unfished biomass in 2004
- O'Neill et al. (2014a) used the annual age structured model from O'Neill et al. (2005) for the Queensland part of the stock. Results estimated that the exploitable biomass was slightly above the biomass that would produce MSY ($B_{2013}/B_{MSY} = 1.07$). This suggested the stock had recovered from earlier estimates of biomass depletion in 2002 and 2004 that were below the level for MSY (O'Neill et al. 2003; O'Neill et al. 2005). The assessment in 2014 estimated a MSY of 1363 t for the Queensland stout whiting fishing sector and a yield of 850 t for 60% biomass
- O'Neill et al. (2016) used catch rate and survival indicators to estimate the Queensland TACC for the 2016 fishing year between 1000–1100 t

- Wortmann et al. (2016) used catch rate and survival indicators to estimate the Queensland TACC for the 2017 fishing year between 1100–1130 t
- Hall (2019) showed that stout whiting standardised catch rates in the New South Wales prawn trawl fishery fluctuated between 10 and 15 kg/hour since 2010, after increasing from a low in 2000. This pattern also is reflected in the catch rate from Evans Head and Yamba (29 °S), where most of the catches of stout whiting were taken
- Wortmann (2020) used catch rate analysis to estimate the Queensland TACC for the 2021 fishing year between 1123–1284 t.

The proposed harvest strategy for the Queensland stout whiting fishery (Fisheries Queensland 2020b) will use outputs from this stock assessment that will be run every three years. The aim of the stock assessment is to inform the setting of the total allowable commercial catch (TACC) so that the fishery achieves and maintains a biomass of 60%. In the years between stock assessments, the quota calculations from Wortmann (2020) based on standardised catch rates will be used to guide the TACC setting.

This fishery assessment report describes the commercial stout whiting fishery operating along Australia's east coast. The report was prepared to inform Fisheries Queensland and Queensland licence holders on the 2020 fishing year stock biomass.

2 Methods

2.1 Data sources

Data on which the assessment was based (Table 2.1) are described in more detail in the following sections. The data were used to determine catch rates, age and length compositions, and create annual harvests. These were summarised and modelled by sector. Preparation of data was compiled by fishing year. For stout whiting, fishing year was defined to be the same as financial year, 1 July 2019–30 June 2020 was the 2020 fishing year. The assessment period began in 1945 up until and including June 2020 based on available information.

Table 2.1: Data inputs for the population model

Type	Fishing year	Source
Commercial harvest	1991–2020	Logbook data collected by Fisheries Queensland
	2000–2020	Buyer returns from Queensland fishers
	2004–2020	Quota management system
	1997–2020	Logbook data collected by Department of Primary Industries, New South Wales
Historical harvest	1945–1990	Estimation of Queensland harvest (O'Neill et al. 2005)
	1945–1997	New South Wales data records (Hall 2019)
Bycatch discards from prawn trawl	1945–2020	Estimation of stout whiting bycatch from the Queensland prawn trawl fishery (Robins et al. 2000; Courtney et al. 2007)
	1945–2020	Estimation of stout whiting bycatch from the New South Wales Ocean Trawl Fishery (Hall 2019)
Biological	1991–2015	Length and age data from fishery dependent monitoring undertaken by Fisheries Queensland (O'Sullivan et al. 2007)
Lunar	1991–2020	Continuous daily luminous scale of 0 (new moon) to 1 (full moon) (O'Neill et al. 2014b)
Weather	1991–2020	Bureau of Meteorology
Seasonality	1991–2020	Seasonal patterns corresponding to autumn, winter, spring and summer periods (Mariott et al. 2014)

2.1.1 Regions

The stock was modelled as a single stock, covering the Queensland east coast and New South Wales ocean zones OZ1 - Cape Byron and Ballina (28 °S), OZ2 - Evans Head and Yamba (29 °S), OZ3 - Coffs Harbour (30 °S) and OZ4 - Port Macquarie (31 °S) (Figure 2.1).

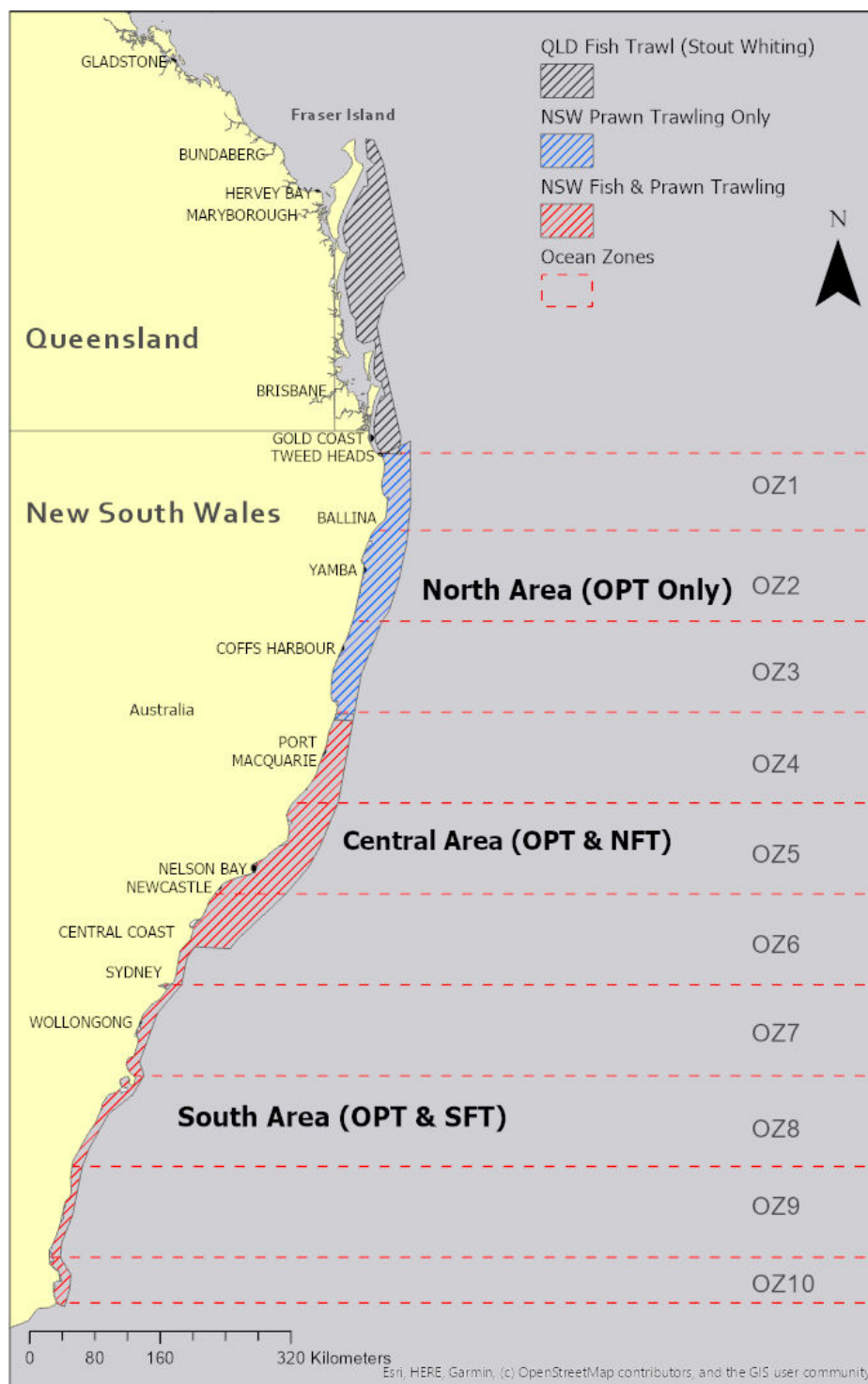


Figure 2.1: The east coast stout whiting fishery

2.1.2 Commercial

Daily Queensland commercial catches from each vessel on a trawl shot basis were collated by Southern Fisheries Centre from 1991 to 1999. Catches from 2000 to 2020 were extracted from the Queensland Fisheries CFISH logbook data. The logbooks recorded catch in number of cartons and a weight multiplier was given at the end of the season. The daily logbooks recorded the location of the catch (30 minute or 6 minute grid identifier) and the number of trawl shots. Trawl shots where no stout whiting were caught, although were targeted, were included.

For New South Wales, monthly data for the period July 1997–June 2009, where effort in number of days fished per month and weight of catch in kilograms were provided. Daily event data for the period July 2009–June 2019 were provided, with effort in number of hours trawled and weight of catch in kilograms. Since July 2009, catches have been reported as daily fishing events with number of hours trawled provided for effort.

New South Wales commercial logbooks prior to July 2009 did not require fishers to report eastern school whiting and stout whiting separately, and catches were reported as mixed ‘school whiting’ or ‘trawl whiting’. Although new daily logbooks were introduced in July 2009 that legally required fishers to accurately report landed catches of the two species separately, considerable misreporting is still known to occur, especially in northern New South Wales waters (OZ1–OZ2), with stout whiting often reported as eastern school whiting (Hall 2019).

2.1.3 Bycatch

The magnitude of stout whiting bycatch from the Queensland prawn trawl sector was gauged by the number of prawn trawl boat days of fishing effort. The methodology used was from previous stout whiting stock assessments (O'Neill et al. 2005; O'Neill et al. 2014a). Lower and higher bycatch scenarios were determined by reducing or increasing the prawn trawl boat days of fishing effort by a quarter.

Historically, most stout whiting were discarded in New South Wales waters, but from 1998 fishing year stout whiting were retained more and currently discard rates are around 27.7% (Hall 2019).

2.1.4 Historical

Historical annual catch data by ocean zone in kilograms from the Ocean Trawl Fishery in New South Wales were available for 1945–1983. Historical data did not report eastern school whiting and stout whiting separately, and catches were reported as mixed ‘school whiting’ or ‘trawl whiting’. Furthermore, historical catches of ‘trawl whiting’ were often combined with other species in ‘mixed whiting’ or ‘unspecified whiting’ catches. Closer examination of these data suggested that a large proportion was from estuarine waters and were more likely to be sand whiting (*Sillago ciliata*) or trumpeter whiting (*Sillago maculata*). Only catches of mixed or unspecified whiting from ocean zones were included in trawl whiting catches.

2.1.5 Age and length compositions

The Fishery Monitoring program, part of Fisheries Queensland, collected fishery dependent data from commercial fishers (O'Sullivan et al. 2007). The sampling details were:

- two 5 kg boxes were collected from each vessel's fishing trip
- all fish from each box were measured
- pre-2000 the first 30 fish from every size class were dissected to extract otoliths and measure gonad weight and age (post-2000 length stratified collection of otoliths was adopted and the weighing of gonads was stopped).

Data collected includes the date the fish was caught, catch location, species name, lengths (cm) and age (years). Data were collected in 1991–2015 for stout whiting and this was used in the stock assessment.

2.2 Harvest estimates

Commercial harvest were analysed to reconstruct the history of harvest from 1945 until the end of 2020 financial year. Prior to 1945 stout whiting harvest was presumed to be small. This section describes how the data were combined to create the history of stout whiting harvest.

Stout whiting was caught as bycatch when the Queensland prawn trawl fishery started around 1959 (Helidoniotis et al. 2020). The stout whiting fishery started in 1981 on the south coast of Queensland with one operator fishing for eastern school whiting and progressively moved to target stout whiting as exploration of new grounds provided evidence that a commercial fishery existed for this species (O'Neill et al. 2003).

New South Wales reported small (less than one tonne) stout whiting catch in 1945.

All harvest input to the model that was retained (landed) was for stout whiting species and was for the whole of the Queensland east coast and New South Wales ocean zones OZ1–OZ4. Further south few stout whiting occur and catches were dominated by eastern school whiting (Figure 2.1).

Queensland commercial sector harvest:

- estimates for the years 1991–2020 were calculated from logbook records. Harvest weight in the logbook data equaled the number of cartons multiplied by the weight per carton determined either from the buyer returns or where available from the quota management system
- estimates for the years 1945–1990 were determined by fitting a generalized linear regression model to the logbook data from the years 1991–1996 as described in O'Neill et al. (2005) and O'Neill et al. (2014a).

New South Wales commercial sector harvest:

The stock assessments in O'Neill et al. (2005) and O'Neill et al. (2014a) estimated stout whiting catch using slightly different adjustment rules for the New South Wales raw catch and effort data. The catch trends for stout whiting produced from these adjustment methods and the method used for this stock assessment were similar (figure 5 verses figure A6 in (Hall 2019)).

- all trawl whiting catches from monthly logbook records 1997–2020 were combined in each of OZ1 and OZ2 zone and then reallocated as 100% stout whiting in OZ1 and 50% to each species in

OZ2. Catches in OZ3 and further south were left as reported, because in these zones, historically few stout whiting were retained

- a large quantity of trawl whiting catch in 2016–2018 was reported without accurate location information, which prevented it from being included in data adjustments and hence catch totals. No capture locations were provided, so they could have been from any or all fishing zones
- all trawl whiting catches for 1945–1996 were combined in each of OZ1–OZ4 and then reallocated as 90% eastern school whiting and 10% stout whiting in each zone to reflect changes in discarding practices.

Queensland discarded bycatch from the prawn trawl fishing sector as described in O'Neill et al. (2005) was estimated by adjusting the estimated effort (estimated because records with effort of greater than one day were set to one day) from the prawn logbook data by a bycatch reduction device (BRD) multiplier, a grid-depth multiplier and the stout whiting Queensland commercial standardised catch rate relative to the overall mean:

- the prawn trawl logbook data 1988–2020 were summarised by year, month, grid and effort where each fisher day record was counted as one days effort. The number of records with duration greater than 1 day was small (1%), and these records were set to effort of one day and included in the summary dataset by year, month, grid and effort
- the BRD multiplier and grid-depth multiplier were estimated using statistical analyses (O'Neill et al. 2005) from three data sets on bycatch of stout whiting by prawn trawlers (Robins et al. 2000; Courtney et al. 2007)
- the annual uptake of BRD's and the brd multiplier (O'Neill et al. 2005), (Appendix A.4) was given by the formula from O'Neill et al. (2005) $1 + (1 - BrdmMultiplier)/MeanBrd$ where $MeanBrd = 0.5201382$ was calculated in O'Neill et al. (2005) and is the effect of BRD, meaning that BRD reduces stout whiting catch to 0.5201 of non-BRD catch
- the grid–depth multiplier depended on the depth of each grid which assigned a fraction of stout whiting caught (O'Neill et al. 2005) multiplied by 302.33651 kg which was statistically calculated from bycatch surveys as the average catch of stout whiting caught per night in O'Neill et al. (2005)
- estimates for the years 1945–1987 were determined by fitting a generalized linear regression model to the logbook data from the years 1988–1992.

New South Wales discard from the Ocean Trawl Fishery was calculated as:

$$discard = catch / (1 - d) - catch \quad (2.1)$$

where $d=0.277$ for financial year 1997 onwards and $d=0.826$ otherwise (K. Hall 2021, pers. comm., 02 February).

2.3 Abundance indices

Logbook data on commercial catches (kg whole weight) of stout whiting per fishing operation–day were used as an index of legal-sized fish abundance. The indices were standardised by removing the effects of a number of factors not related to abundance. Catch rates were calculated in the statistical software GenStat (International 2019). Catch rates were in kilograms per fishing operation day and were scaled relative to the overall mean catch rate for 1991–2020. The methods below outline the concepts and procedures used to achieve this standardisation. In the following, the term “catch rate” refers to a standardised catch rate unless otherwise specified.

2.3.1 Queensland commercial catch rates

From the initial logbook data set, a series of filters were applied to arrive at the final analysis data set. These filters involved a number of criteria relating to location, species, fishing method, fishing date and trip duration. The resulting data set had a maximum of one record per fishing operation per day. A fishing operation was defined by a vessel, fishing method and owner to account for changes in vessel ownership or fishing method. Records for net shots of zero stout whiting catch were included in the final data set. More details on the data filtering process are given in Appendix A.2.

Catch rates of stout whiting were analysed by fishing year and zones (Figure 2.2, Table 2.2). Of the total stout whiting records in the logbook data (1991–2020), 1.4% of the total records were not in these zones. An area weighted approach was used to calculate the overall Queensland commercial catch rate.

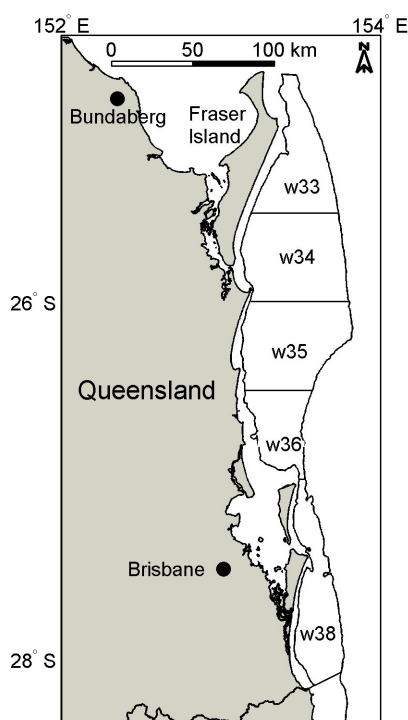


Figure 2.2: Queensland zones for catch rate analysis

Table 2.2: Queensland zones for catch rate analysis

Catch rate zone	Logbook grid	Grid name in Figure 2.2
Fraser Island north	w32, x32, w33, x33	w33
Fraser Island south	w34, x34	w34
Sunshine Coast to Double Island Point	w35, x35	w35
Caloundra	w36, x36	w36
Stradbroke Island and Gold Coast	w37, x37, w38, x38, w39, x39	w38

The catch rate model was a hierarchical generalized linear model (HGLM), (Appendix 1 of Wortmann et al. (2016)). This model was used because the stout whiting fleet was small (there were only 2–5

vessels fishing per year) and the HGLM model allowed for unequal variances between vessels and the random occurrence of zero catch. Factors (daily data) in the catch rate standardisation were:

- fishing year (from logbooks)
- region (from logbooks)
- fishing operation (from logbooks)
- hours fished (from logbooks)
- water depth (from logbooks)
- seasonality (Appendix A in Wortmann (2020))
- lunar phase (Appendix A in Wortmann (2020))
- fishing experience (Appendix A in Wortmann (2020))
- wind speed and direction (Appendix A in Wortmann (2020))
- the use of sonar (Appendix A in Wortmann (2020)).

2.3.2 New South Wales commercial catch rates

From the initial daily logbook data set, a series of filters were applied to arrive at the final analysis data set. These filters involved a number of criteria relating to location, species, fishing method, fishing date and trip duration. The resulting data set had a maximum of one record per fishing operation per day. A fishing operation was defined by a vessel. There were no records for zero stout whiting catch in the logbook data. More details on the data filtering process are given in Appendix A.3.

Catch rates of stout whiting were analysed by fishing year and zones (Table 2.3). Of the total stout whiting records in the logbook data (2009–2019) 2% were not in these zones. An area weighted approach was used to calculate the overall New South Wales commercial catch rate.

Table 2.3: Zones used for New South Wales catch rate analysis

Catch rate zone	Latitude
OZ1	28 °S
OZ2	29 °S
OZ3	30 °S

For New South Wales, the analysis used a generalised linear model (GLM) and considered the model terms (daily data) for:

- fishing year (from logbooks)
- ocean zone (from logbooks)
- boat (from logbooks)
- hours fished (from logbooks)
- seasonality (Appendix A in Wortmann (2020))
- lunar phase (Appendix A in Wortmann (2020))
- wind speed and direction (Appendix A in Wortmann (2020))
- target, where targeting stout whiting was defined where prawn harvests were < 60th percentile of the prawn harvest distribution (Courtney et al. 2014).

2.4 Age and length data

Although stout whiting were aged in 1991 and 1992, these were not from samples in the commercial fishery. The age data were collected as part of sampling for a research project. Thus age frequency

data were statistically calculated for the years 1991–1992 using the age data from 1993–1994 (O’Neill et al. 2005).

2.5 Biological information

2.5.1 Growth curve

The growth curve for stout whiting was given by

$$FL(age)_{cm} = 22.29 \times (1 - \exp(-0.4959 * (age + 1.03))) \quad (2.2)$$

where $FL(age)$ is fork length (cm) at age and age is the age in years (Butcher et al. 1995).

2.5.2 Fecundity and maturity

Maturity values in the model were age-based, following the result of an analysis by O’Neill et al. (2005):

- 82% mature at age 1
- 96% at age 2
- 98% at age 3
- 99% at age 4
- fully mature from age 5.

The fecundity relationship was from O’Neill et al. (2003), O’Neill et al. (2005), and O’Neill et al. (2014a).

2.5.3 Weight and length

The weight–length relationship was given by Butcher et al. (1995)

$$W = 1.382 \times 10^{-5} \times L^{2.879} \quad (2.3)$$

where W is weight (kg) and L is the fork length (cm).

2.6 Population model

A single-sex population dynamic model was fitted to the data to determine the number of stout whiting in each year and each age group using the software package Stock Synthesis (SS; version SSV3.30.15.0). A full technical description of Stock Synthesis is given in Methot et al. (2019).

2.6.1 Model assumptions

Assumptions for formulating inputs to the stout whiting model included:

- The fishery began from an unfished state in 1945
- The fraction of fish that were female at birth was 50% and remained so throughout an individual's life
- Growth occurred according to the von Bertalanffy growth curve
- The weight and fecundity of stout whiting were parametric functions of their size
- The proportion of mature fish depended on age and not size
- The instantaneous natural mortality rate did not depend on age, size or sex
- The age and length frequency for the Queensland commercial fleet were applied to New South Wales commercial fleet

- The Queensland commercial fleet consisted of stout whiting catch from the stout whiting fishing sector and bycatch from the prawn trawl fishing sector
- The New South Wales commercial fleet consisted of stout whiting catch from the ocean prawn trawl fishery and discards (all discards were dead).

2.6.2 Model parameters

A variety of parameters were included in the model, with some of these fixed at specified values and others estimated. Uniform priors were used unless stated otherwise.

The natural logarithm of virgin spawning stock size ($\ln(R_0)$) was estimated within the model. The parameter $\ln(R_0)$ was the natural logarithm of the number of recruits in 1945.

Stock recruitment steepness (h) was estimated within the model. This is an important productivity parameter in the model.

Natural mortality (M) was fixed within the model to 0.6996 per year (Butcher et al. 1995).

Parameters of the von Bertalanffy growth curve were fixed within the model, including coefficient of variation for old fish.

Logistic length-based selectivity parameters were estimated for the model fleets. Separate selectivity curves were estimated for each fishery fleet based on length data obtained from the fisheries dependent monitoring programs, although for this stock assessment the length data available were for Queensland only. Thus the New South Wales selectivity mirrored the Queensland selectivity.

Recruitment deviations between 1991 and 2020 improved fits to composition data and abundance indices as variability in recruitment annually allowed for changes in the population on shorter time-scales than fishing mortality alone.

2.6.3 Model weightings

All data inputs were given equal weighting in the model, however a Francis weighting was applied to the age and length compositions (Francis 2011).

2.6.4 Sensitivity tests

Six additional model runs were undertaken to determine sensitivity to fixed parameters and model inputs. The sensitivities were as follows:

- Natural mortality parameter of 0.55 (Butcher et al. 1995) and 0.85 (O'Neill et al. 2005)
- Reduced and increased trawl bycatch from the Queensland prawn trawl fishing sector.

The summary statistics presented for these were:

- The virgin spawning stock biomass SB_0
- The spawning stock biomass in 2020 SB_{2020}
- The current biomass ratio, i.e. SB_{2020}/SB_0
- The negative log-likelihood value $-\ln L$
- Recommended biological harvest at 60% equilibrium biomass.

2.6.5 Forward projections

Stock Synthesis's forecast sub-model was used to provide forward projections of biomass and future harvest targets, following the harvest control rule to reach 60% unfished biomass by 2040. This harvest control rule has a linear ramp in fishing mortality between 20% exploitable biomass, where fishing mortality is set at zero, and 60% exploitable biomass, where fishing mortality is set at the equilibrium level that achieves 60% biomass (F_{B60}). Below 20% exploitable biomass fishing mortality remains set at zero, and above 60% exploitable biomass fishing mortality remains set at F_{B60} (Figure 2.3). This shifting rate starts out small, which enables the stock to recover much more quickly and means that harvests are not impacted for as long. This rule can be augmented with a “buffer” to offset model uncertainty. A buffer is a discount factor applied to the control rule to account for risk under uncertainty. For this assessment, a buffer value of 0.87 has been chosen for some harvest scenarios following the stout whiting draft Harvest Strategy policy guidelines (Fisheries Queensland 2020a).

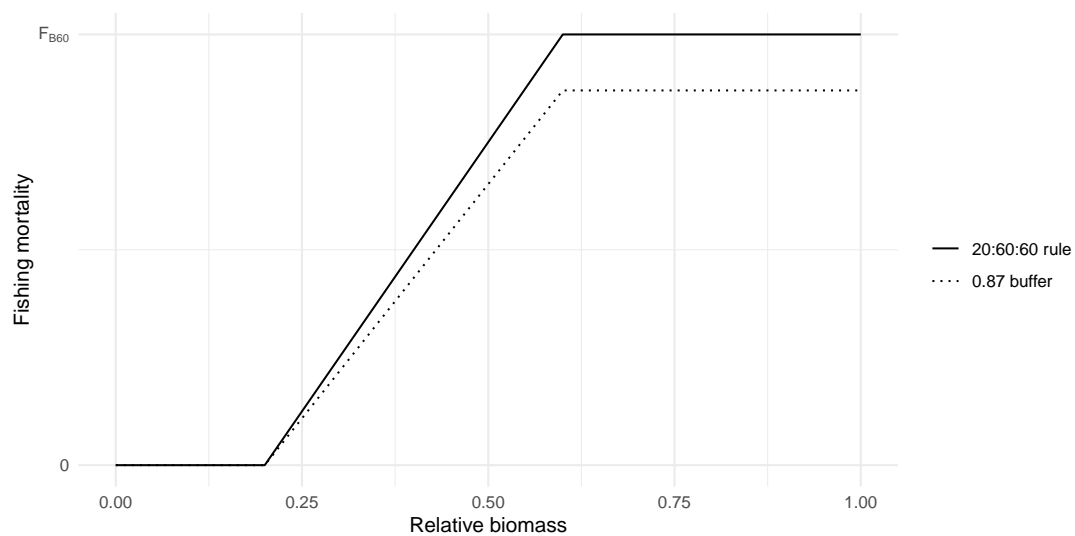


Figure 2.3: The 20:60:60 harvest control rule (solid line) with 0.87 buffer (dashed line)

3 Results

3.1 Model inputs

The model inputs and outputs relate to the base case scenario where natural mortality was 0.6996 per year and bycatch from the Queensland prawn trawl fishery was determined from the number of boat days of effort as recorded from the logbooks.

3.1.1 Harvest estimates

The majority of the total harvest can be attributed to Queensland. Prior to 1980, the total harvest was relatively low (Figure 3.1). The harvest estimates indicated that over 2000 t of stout whiting were landed annually by the Queensland commercial stout whiting fishing sector in the late 1990s. In recent years the estimated Queensland commercial harvest from the stout whiting fishing sector has reduced to just over 1000 t annually, which is close to the TACC. Bycatch estimates from the prawn trawl sector are for a similar tonnage. The component split over the last five years is shown in Table 3.1.

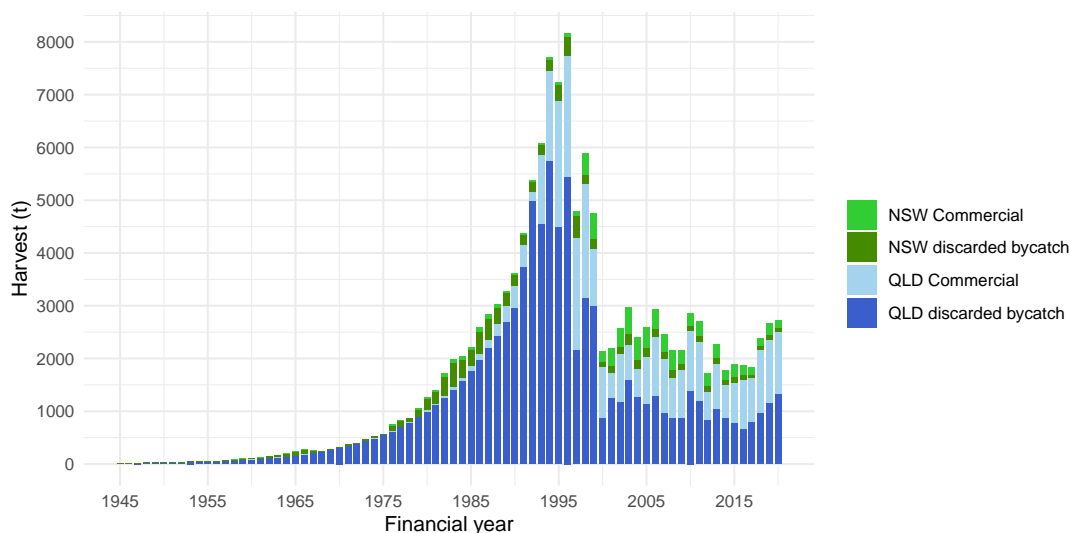


Figure 3.1: Annual estimated harvest from commercial sectors between 1945 and 2020

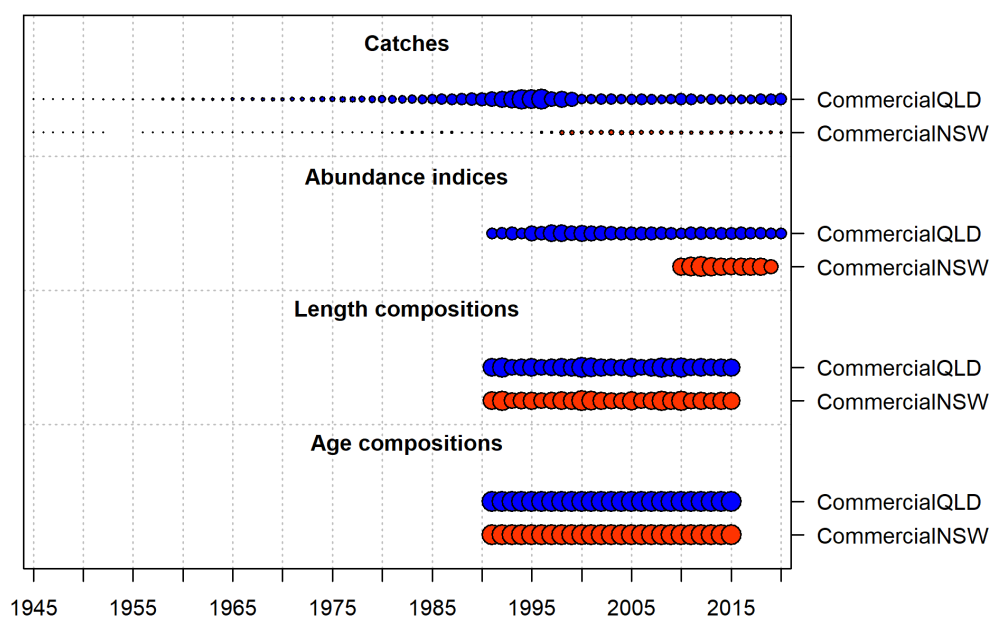


Figure 3.2: Data presence by year for each category of data type and Stock Synthesis fleet

Note: Circle areas are proportional to total harvest for harvests - to precision for indices and discards; and to total sample size for compositions - the scaling within separate plots should not be compared

Table 3.1: Proportion of harvest for financial years 2016–2020

Fishing sector	Proportion
Queensland commercial	46%
Queensland discarded bycatch	43%
New South Wales commercial	8%
New South Wales discarded bycatch	3%

3.1.2 Standardised catch rates

The Queensland commercial standardised catch rate index declined from 2013 to 2016 from above the long term mean to below the long term mean (Figure 3.3). From 2016 catch rates recovered to above the long term mean in 2019 and 2020. Catch rate diagnostics are in Section B.3.3 (Figure B.7).

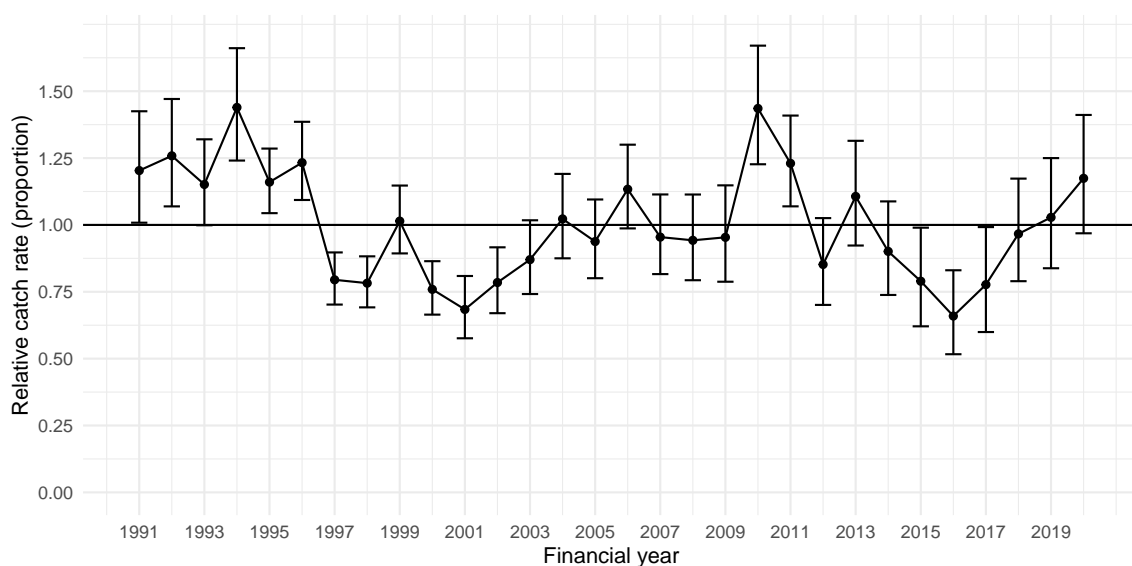


Figure 3.3: Annual relative standardised catch rates and 95% confidence interval for the Queensland stout whiting fishery from January 1991 to May 2020

The New South Wales commercial catch rate index decreased from 2015 to 2018 from above the long term mean to below the long term mean (Figure 3.4). Catch rates recovered in 2019 to a historic highest level above the long term mean. Catch rate diagnostics are in Section B.3.3 (Figure B.8).

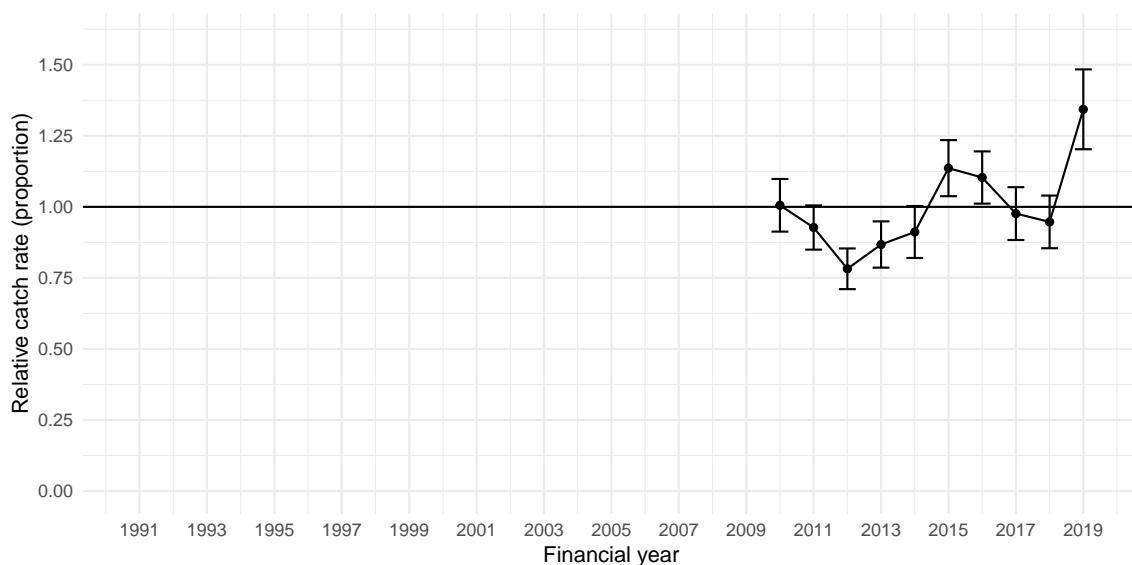


Figure 3.4: Annual relative standardised catch rates and 95% confidence interval for the New South Wales stout whiting fishery from July 2009 to June 2019

3.1.3 Age composition

Fishery age-composition data were input to the population model, as part of age-at-length compositions (Figure 3.5). Strong year classes were not observed from year to year. In 2014 there was a higher frequency of two year old fish, extending from the high frequency of one year old fish in 2013. The sample sizes are given in Appendix A.1.

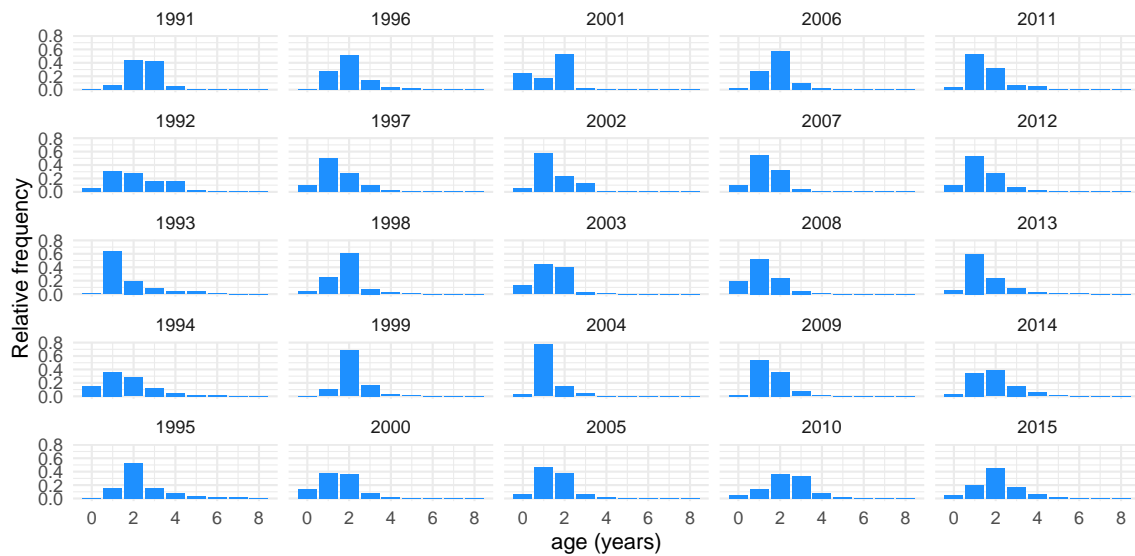


Figure 3.5: Age frequency of stout whiting for commercial-caught fish between 1991 and 2015 in Queensland

3.1.4 Length composition

Fishery length compositions were input to the population model for Queensland (Figure 3.6). Strong year classes were not observed from year to year. The sample sizes are given in Appendix A.1.

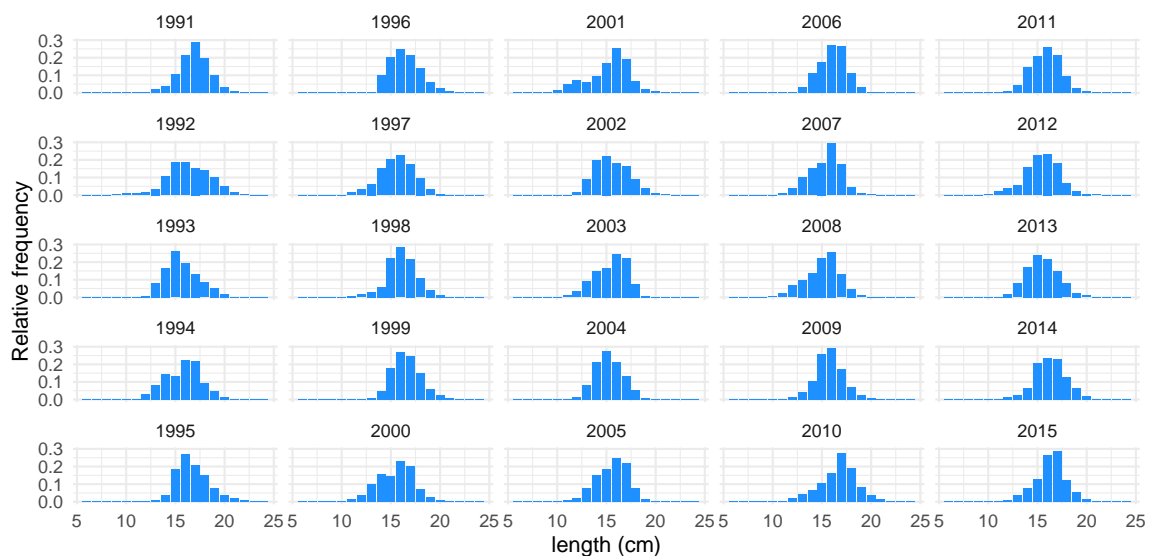


Figure 3.6: Length frequency of stout whiting for commercial-caught fish between 1991 and 2015 in Queensland

3.2 Model outputs

3.2.1 Model parameters

Several parameters were estimated within the model (Table 3.2). The full list of estimated parameters is given in Appendix B, Table B.2.

Table 3.2: Summary of parameter estimates from the base population model

Parameter	Estimate	Standard deviation
CV young Fem GP1	0.10	0.01
logarithm of the number of recruits in 1945 (R_0)	20.17	0.08
steepness (h)	0.36	0.02
logarithm of the catch multiplier CommercialQLD ($\ln(Q_{base})$)	-15.69	0.12
logarithm of the catch multiplier CommercialNSW ($\ln(Q_{base})$)	-15.66	0.14
CommercialQLD selectivity ascending inflection (cm) (p_1)	14.23	0.20
CommercialQLD selectivity ascending width (cm) (p_2)	1.93	0.21
CommercialNSW selectivity ascending inflection (cm) (p_1)	14.19	0.21
CommercialNSW selectivity ascending width (cm) (p_2)	1.90	0.21

3.2.2 Model fits

Good fits were achieved for abundance indices (Appendix B.2.1). For some years there were differences between the model estimates and the observed age and length frequencies, particularly for longer fish for the years 1991–1993, 1996, 1997, 2001 and 2003–2006 (Appendix B.2.2 and Appendix B.2.3).

If the model estimated the L_∞ parameter in the von Bertalanffy growth equation, then the estimate for L_∞ was too low (18 cm). If the model estimated the natural mortality parameter then the estimate was too high (1.23 per year). In addition the length composition fits estimated by the model were poor. This suggested that there were some other factors at play not accounted for in the model in the mortality of stout whiting (e.g. environmental).

The selectivity of stout whiting was estimated within the model (Appendix B.2.4).

3.2.3 Biomass

The model predicted that spawning stock biomass declined between 1981 and 2000 to 27% unfished biomass. In 2020, the stock level was estimated to be 42% unfished spawning biomass (Figure 3.7).

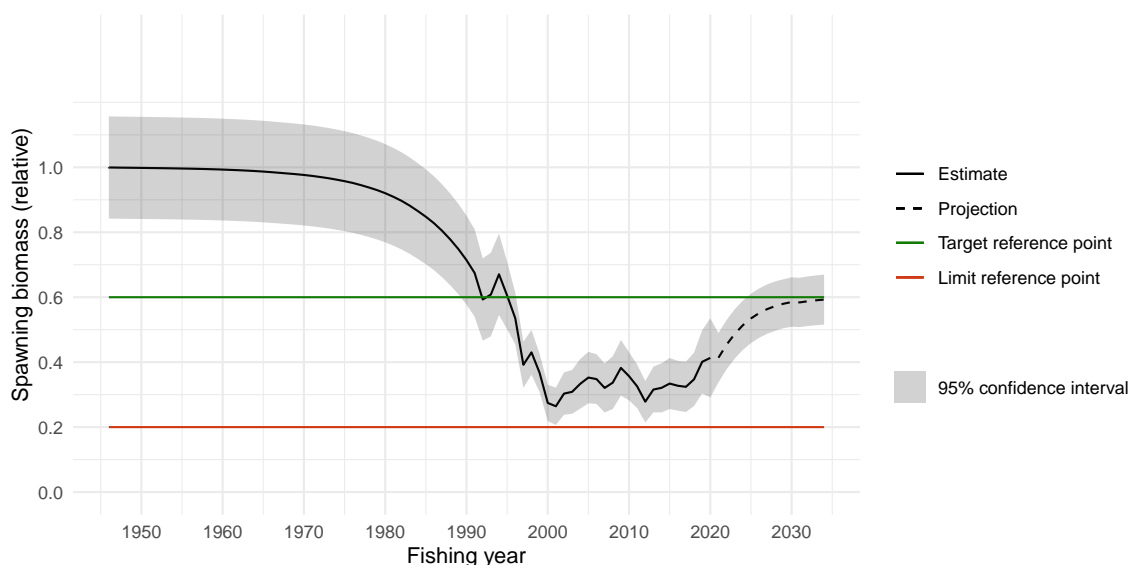


Figure 3.7: Predicted spawning biomass trajectory relative to unfished, from 1945 to 2040 financial year—refer to Section 2.6.5 for a description of the projection phase (2021–2040)

The relationship between the biomass estimate and fishing mortality are presented in a phase plot (Figure B.6 in Appendix B.3.1).

The equilibrium harvest informs on the productivity of the stock at different biomass levels (Figure 3.8). The maximum sustainable yield occurs at 42% unfished biomass and is 3259 t. This includes the Queensland and New South Wales commercial fishing sectors and the bycatch from the Queensland prawn trawl fishing sector.

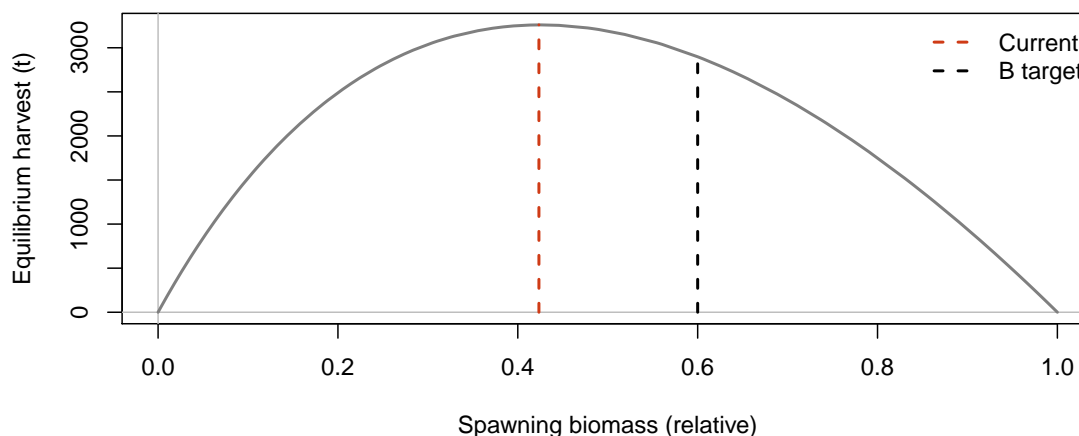


Figure 3.8: Equilibrium yield curve

3.2.4 Harvest targets

Harvest targets were calculated to build spawning biomass to the 60% target reference point over 20 years, with a recommended biological catch (RBC) of 2018 t using the 20:60:60 harvest control rule with a 0.87 buffer (Table 3.3). Appendix B shows RBCs for sensitivity runs (Table B.3). The harvest targets included the bycatch from the Queensland prawn trawl fishing sector.

Table 3.3: Estimated total harvests and biomass ratios of stout whiting to rebuild to the target reference point of 60% unfished spawning biomass in 20 years, following a 20:60:60 control rule with 0.87 buffer

Year	Harvest (t)	Biomass ratio
2021	2018	0.42
2022	2184	0.45
2023	2324	0.48
2024	2440	0.50
2025	2536	0.52
2026	2613	0.54
2027	2675	0.55
2028	2725	0.56
2029	2764	0.57
2030	2794	0.58
2031	2818	0.58
2032	2836	0.59

3.2.5 Sensitivities

Table 3.4: Summary of results from the base case and the sensitivity tests. Lower values for the comparable likelihoods ($-LnL$) are indicative of a better fit

Model	$-LnL$	$SB_0(t)$	$SB_{2020}(t)$	Harvest at 60% biomass ratio (t)	SB_{2020}/SB_0
base case	118.2	4.71×10^{10}	1.98×10^{10}	2897	0.42
$M = 0.55$	130.45	4.12×10^{10}	1.50×10^{10}	2758	0.36
$M = 0.85$	110.63	5.75×10^{10}	2.75×10^{10}	3008	0.47
reduced bycatch	115.12	3.76×10^{10}	1.83×10^{10}	2664	0.48
higher bycatch	121.49	5.73×10^{10}	2.12×10^{10}	3190	0.36

4 Discussion

4.1 Stock status

Results from this assessment suggested the stout whiting population on the Queensland and New South Wales east coast experienced decline in the period from 1980 to 2000. Population levels stabilised in the period from 2001 to 2016, followed by some recovery in the period from 2017 to 2020. The current (2020) population level is around 42% of unfished spawning biomass. The results also suggested that catch levels during 1988–2003 were higher than would be consistent with a 60% target reference point.

Results from the eastern school whiting stock assessment in Commonwealth of Australia (2020) suggested that the eastern school whiting population (mainly from New South Wales waters) experienced decline from 1952 to a minimum biomass of 28% of unfished spawning biomass in 1999. Population levels increased from 2000 to over 40% unfished biomass between 2006 and 2009 followed by another decline to 29% in 2014. Since then to 2018, biomass has varied between 30 and 40% unfished biomass.

4.2 Performance of the population model

A number of sensitivities were tested to better understand which assumptions and parameters are most influential on the model. Assumptions surrounding natural mortality were influential. If the model estimated natural mortality, then this was estimated at biologically unrealistic high values of 1.25 per year and then the model also estimated a very high steepness of 0.99. Thus natural mortality was fixed at the published value of 0.6996 per year.

If the L_{∞} parameter in the von Bertalanffy growth equation was estimated then the model estimated a maximum length of 18 cm instead of the published value of 22.29 cm. Estimation of L_{∞} improved the length composition fits, but then the L_{∞} parameter did not represent stout whiting growth and steepness was estimated high at 0.99. Thus the L_{∞} parameter was fixed at the published value.

Model limitations of note included:

- regional variation in biological characteristics was not taken into account
- the current assessment assumed a reproductive mechanism (males and females in fixed 50% proportion from birth) as there is no published evidence thus far of hermaphroditism in stout whiting
- the assumption that the age and length compositions of Queensland and New South Wales were the same meant that the New South Wales selectivity mirrored the Queensland selectivity
- the extent of bycatch in the Queensland commercial prawn trawl sector remains largely unknown. A lower case scenario and upper case scenario were considered. It is likely that the lower case scenario was more applicable for this stock assessment because in calculating the trawl effort records for all fishing gear were considered. There is anecdotal evidence that prawn trawlers using quad-gear generally do not catch much stout whiting as bycatch, compared to boats using triple-gear. Further, anecdotal evidence suggests that boats fishing at depths greater than 40 fathoms have minimal interactions with stout whiting. However, more information is required.
- In 2002 additional work was funded to verify the accuracy of aging stout whiting and whether whole or sectioned ageing was the preferred method (O'Neill et al. 2003). A total of 500 stout whiting otoliths from the 2001 fishery were forwarded to the Central Aging Facility, Marine and Freshwater

Resources Institute, Victoria, to age. They concluded that ages from whole otoliths would be appropriate for routine stock assessment.

4.3 Recommendations

4.3.1 Data

Commercial data utility would be improved by accurate effort measures with fishing time and accurate location recorded for each commercial operation. Electronic reporting systems may be valuable for achieving these objectives.

Automated updates of average carton weight from the live quota management system to the Queensland commercial logbooks would streamline the estimation of stout whiting weight caught from logbook records.

Bycatch data from the prawn trawl fishing sector could be improved by the reporting of stout whiting weight discarded by prawn trawlers in Queensland.

Better species identification between stout whiting and eastern school whiting in the New South Wales logbooks would benefit future assessments.

4.3.2 Monitoring

The discontinuation of the Fisheries Queensland monitoring surveys at the end of 2015 led to greater uncertainty in model outputs. It is recommended that the monitoring program continues on an annual basis and that the data it provides is included in the next assessment as soon as possible.

It is recommended that New South Wales age and length data be included in the next assessment and that the data should be comparable with the Queensland data.

The availability of length data for stout whiting bycatch from the Queensland prawn trawl fishery would help in having the bycatch as a separate fleet in the model with its own selectivity pattern.

4.3.3 Management

Maximum sustainable yield was estimated at 3259 t per year. This included the Queensland and New South Wales commercial fishing sectors and the bycatch from the Queensland prawn trawl fishing sector. The harvest consistent with a biomass ratio of 60% (a proxy for maximum economic harvest) was estimated at 2897 t (all sectors).

The stock assessment showed the state of the stock is at just over 40%, and for this reason the recommended biological harvest in calendar year 2021 to achieve the *Queensland sustainable fisheries strategy 2017—2027* longer term target of 60% unfished biomass may be up to 2018 t (all waters and sectors). This recommended biological harvest would be increased to 2897 t over time.

Management action in the early 2000s to set the Queensland TACC appears to have put stock levels on a sustainable track. The *Queensland sustainable fisheries strategy 2017—2027* is a sensible way to maintain this as it is underpinned by a harvest control rule. This can buffer against model uncertainty and should remain responsive as modelling and data improve.

4.3.4 Assessment

Limitations with the performance of the current model have been discussed in this document. Specific recommendations for a future assessment are as follows:

- the appropriateness of a two-region model (Queensland and New South Wales) be considered
- the assessment incorporates newly available age and length composition data from Queensland and New South Wales. Age and length composition data for New South Wales would enable the estimation of a separate selectivity function for New South Wales.

4.4 Conclusions

This assessment has informed the status of the stout whiting population on the east coast of Queensland and New South Wales. It suggests that current harvest levels are around 40% and that under the *Queensland sustainable fisheries strategy 2017—2027*, rebuilding is required to build up to the target reference point. The results provide recommended biological catch using a 20:60:60 control rule. Some limitations of the assessment have been noted and recommendations made.

References

- Butcher, A. and I. Brown (1995). *Age-structure, growth and reproduction of stout whiting *Sillago robusta* and Japanese market trials*. FRDC report no 92/101. Tech. rep. Brisbane: Fisheries Queensland. URL: <http://era.daf.qld.gov.au/id/eprint/4064/> (visited on 12/08/2020).
- Butcher, A. R. and W. L. Hagedoorn (2003). "Age growth and mortality estimates of stout whiting, *Sillago robusta* Stead (Sillaginidae), from southern Queensland". In: *Asian Fisheries Science* 16, pp. 215–228.
- Commonwealth of Australia (2020). *Fishery status reports 2020*. Tech. rep. Canberra: Australian Bureau of Agricultural, Resource Economics, and Sciences. URL: <http://awe.gov.au/abares/publications> (visited on 12/23/2020).
- Courtney, Anthony J., James A. Haddy, Matthew D. Campbell, Darren P. Roy, Mark L. Tonks, Shane W. Gaddes, Keith E. Chilcott, Michael F. O'Neill, Ian W. Brown, Mark McLennan, Edward J. Jebreen, C. van der Geest, Cassandra Rose, S. Kistle, Clive T. Turnbull, Peter M. Kyne, Mike B. Bennett, and J. Taylor (May 2007). *Effects of Trawling Subprogram: Bycatch Weight, Composition and Preliminary Estimates of the Impact of Bycatch Reduction Devices in Queensland's Trawl Fishery*. Tech. rep. Brisbane: Queensland Department of Primary Industries and Fisheries. URL: http://frdc.com.au/research/Documents/Final_reports/2000-170-DLD.PDF (visited on 05/15/2015).
- Courtney, Anthony J., Michael F. O'Neill, J. Matías Braccini, George M. Leigh, Marco Kienzle, Sean Pascoe, A. J. Prosser, You-Gan Wang, Luke Lloyd-Jones, Alexander B. Campbell, Matthew C. Ives, Steven S. Montgomery, and J. Goring (Apr. 2014). *Biological and economic harvest evaluations of the eastern king prawn fishery*. Tech. rep. Final Report, FRDC project no. 2008-019. Canberra: Fisheries Research and Development Corporation. URL: <http://www.frdc.com.au/research/final-reports/Pages/2008-019-DLD.aspx> (visited on 05/17/2017).
- Fisheries Queensland (2020a). *Fin fish trawl (stout whiting) fishery harvest strategy: 2021–2026 CONSULTATION DRAFT*. Tech. rep. Brisbane: Fisheries Queensland. URL: <https://daf.engagementhub.com.au/draft-harvest-strategy-policy> (visited on 12/24/2020).
- (2020b). *Fin Fish Trawl (Stout Whiting) Fishery. Harvest Strategy 2020–2025. CONSULTATION DRAFT*. Tech. rep. Brisbane: Fisheries Queensland. URL: <https://daf.engagementhub.com.au/> (visited on 10/25/2020).
- Francis, R. I. C. Chris (2011). "Data weighting in statistical fisheries stock assessment models". In: *Canadian Journal of Fisheries and Aquatic Sciences* 68.6, pp. 1124–1138. URL: <http://dx.doi.org/10.1139/f2011-025>.
- Gray, C. L., L. M. Barnes, D. van der Leulen, and B. W. Kendall (2017). "Length-and-age-based demographics of exploited populations of stout whiting, *Sillago robusta* Stead". In: *Journal of Applied Ichthyology* 33, pp. 1073–1082.
- Hall, Karina C. (2019). *Stock assessment report 2019 - Ocean Trawl Fishery - Eastern school whiting and stout whiting (Sillago flindersi and Sillago robusta)*. Tech. rep. Coffs Harbour: Department of Primary Industries. URL: era.daf.qld.gov.au/7696/ (visited on 10/25/2020).
- Helidoniotis, F., M. O'Neill, and M. Taylor (2020). *Stock assessment of eastern king prawn (Melicertus plebejus)*. Tech. rep. Brisbane: Fisheries Queensland. URL: <https://daf.engagementhub.com.au/> (visited on 10/25/2020).
- International, VSN (2019). *Genstat for Windows 20th Edition*. Type: Computer Program. VSN International, Hemel Hempstead, UK. URL: Genstat.co.uk.

- Mariott, Ross J., Michael F. O'Neill, Stephen J. Newman, and Craig L. Skepper (2014). "Abundance indices for long-lived tropical snappers: estimating standardized catch rates from spatially and temporally coarse logbook data". In: *ICES Journal of Marine Science: Journal du Conseil* 71.3, pp. 618–627. URL: <http://icesjms.oxfordjournals.org/content/71/3/618.full.pdf>.
- Methot, Richard D., Chantel R. Wetzel, and Ian G. Taylor (2019). *Stock Synthesis User Manual Version 3.30.13*. Tech. rep. Seattle, WA: National Oceanic and Atmospheric Administration, U.S. Dept. Commer., p. 215.
- New South Wales Department of Primary Industries (2007). *Fishery Management Strategy for the Ocean Trawl Fishery*. Tech. rep. New South Wales: Department of Primary Industries.
- O'Neill, M., K. Yeomans, Breddin I., E Jebreen, and A. Butcher (2003). *The Queensland stout whiting fishery 1991–2002*. Tech. rep. Brisbane: Department of Primary Industries. URL: http://fish.gov.au/Archived-Reports/2012/reports/Documents/O'Neill_et_al_2002_Qld_stout_whiting_fishery_1991_to_2002.pdf (visited on 10/25/2020).
- O'Neill, Michael F. and George M. Leigh (2014a). *Queensland Stout Whiting fishery: Commercial quota setting 2014*. Tech. rep. Brisbane: Department of Agriculture and Fisheries.
- (2016). *Stout Whiting Fishery Summary: Queensland total allowable catch for 2016*. Tech. rep. Brisbane: Department of Agriculture and Fisheries. URL: era.daf.qld.gov.au/5200/ (visited on 06/09/2016).
- O'Neill, Michael F., George M. Leigh, You-Gan Wang, J. Matías Braccini, and Matthew C. Ives (Oct. 2014b). "Linking spatial stock dynamics and economics: Evaluation of indicators and fishery management for the travelling eastern king prawn (*Melicertus plebejus*)". In: *ICES Journal of Marine Science* 71.7, pp. 1818–1834. URL: <http://dx.doi.org/10.1093/icesjms/fst218>.
- O'Sullivan, s. and E. Jebreen (2007). *Fisheries Long Term Monitoring Program—Summary of stout whiting (Sillago robusta) survey results: 1991–2006*. Tech. rep. Brisbane: Department of Primary Industries. URL: https://www.daf.qld.gov.au/__data/assets/pdf_file/0008/65627/StoutWhiting-Summary-1991-2006.pdf (visited on 11/11/2020).
- O'Neill, Michael F., Anthony J Courtney, Norm M Good, Clive T Turnbull, Kate M Yeomans, Jonathan Staunton Smith, and Celeste Shootingstar (2005). "Reference point management and the role of catch-per-unit effort in prawn and scallop fisheries". In: *Department of Primary Industries and Fisheries, Queensland, Australia FRDC* 199, p. 120.
- Ovenden, J. and A. Butcher (1999). *An investigation of migration and possible stock structuring by Stout Whiting, Sillago robusta, in southern Queensland waters, and its impact on managing the fishery*. Tech. rep. Brisbane: Department of Primary Industries.
- Robins, J., S. Eayres, M. Campbell, G. Day, and J. McGilvray (2000). *Commercialisation of bycatch reduction strategies and devices within northern Australian prawn trawl fisheries. FRDC project no 96/254*. Tech. rep. Brisbane: FRDC. URL: <http://frdc.com.au/Archived-Reports/FRDC%20Projects/1996-254.80-DLD.pdf> (visited on 11/11/2020).
- Wortmann, Joanne (2020). *Queensland commercial stout whiting (Sillago robusta) fishery: Total allowable catch for 2021*. Tech. rep. Brisbane: Department of Agriculture and Fisheries. URL: era.daf.qld.gov.au/7696/ (visited on 10/25/2020).
- Wortmann, Joanne and Michael F. O'Neill (2016). *Stout Whiting Fishery Summary: Commercial quota setting for 2017*. Tech. rep. Brisbane: Department of Agriculture and Fisheries. URL: era.daf.qld.gov.au/5199/ (visited on 06/09/2016).

Appendix A Model inputs

A.1 Age and length sample sizes

Table A.1: Raw sample sizes measured and aged for commercially caught stout whiting

year	Length	Age
1991	7744	0
1992	4148	0
1993	5505	311
1994	3358	690
1995	6319	465
1996	11 025	444
1997	9276	495
1998	12 588	496
1999	15 822	472
2000	14 169	496
2001	20 151	492
2002	7837	553
2003	6951	487
2004	10 352	496
2005	19 389	632
2006	8235	457
2007	13 460	554
2008	7461	598
2009	6920	529
2010	5492	663
2011	4600	473
2012	3204	485
2013	3198	478
2014	1911	350
2015	2953	473

A.2 Queensland catch rate data filtering

Commercial catch and effort data were extracted from the Queensland logbook database. From this initial set of records, the catch rate analysis data were defined through a series of filters, each of which excluded a number of records.

Catch record data were included or excluded based on the following criteria:

- Excluded catch over multiple fishing days (491 out of 63670 records, 0.8%, 30 out of 30950 t, 0.001%)
- Included catch in 30' by 30' logbook grids from w33 to w38 (63479 out of 63670 records, 99.7%, 30202 out of 30264 t, 99.8%)

- Excluded catch for fishing operation 3 (28 records in fishing year 2000), 7 (1 record in fishing year 1997 and 5 records in 1998), 14 (26 records in 1991) and 15 (46 records in 1991 and 9 records in 1992)
- Included records for net shots of zero stout whiting catch (114 out of 11128 records, 1%).

A.3 New South Wales catch rate data filtering

Commercial catch and effort data were extracted from the New South Wales fishonline logbook database. From this initial set of records, the catch rate analysis data were defined through a series of filters, each of which excluded a number of records.

Catch record data were included or excluded based on the following criteria:

- Included catch for ocean zones OZ1 (28 °S)–OZ3 (30 °S) these records had one method of fishing for stout whiting (Otter trawl net (prawns)) (418 354 out of 435 175 records, 96%, 13 684 out of 15 182 t, 90%)
- Excluded catch for ocean zone OZ4 (31 °S) (16 821 out of 435 175 records, 4%, 1498 out of 15 182 t, 10%) -there were 3 records in Otter trawl net (fish) for stout whiting but these were in Port Macquarie
- Included catch where either stout whiting catch > 0 or eastern school whiting > 0 (26 229 out of 47 780 records, 55%, 9172 out of 13 684 t, 67%)
- Excluded catch where hours fished > 180 hours (6 out of 26 230 records, 0.02%, 1.3 out of 2193 t, 0.06%)
- Hours fished between 23 and 180 were imputed using a normal distribution (397 out of 26 230 records, 2%, 111 out of 2193 t, 5%).

A.4 Bycatch reduction device multipliers

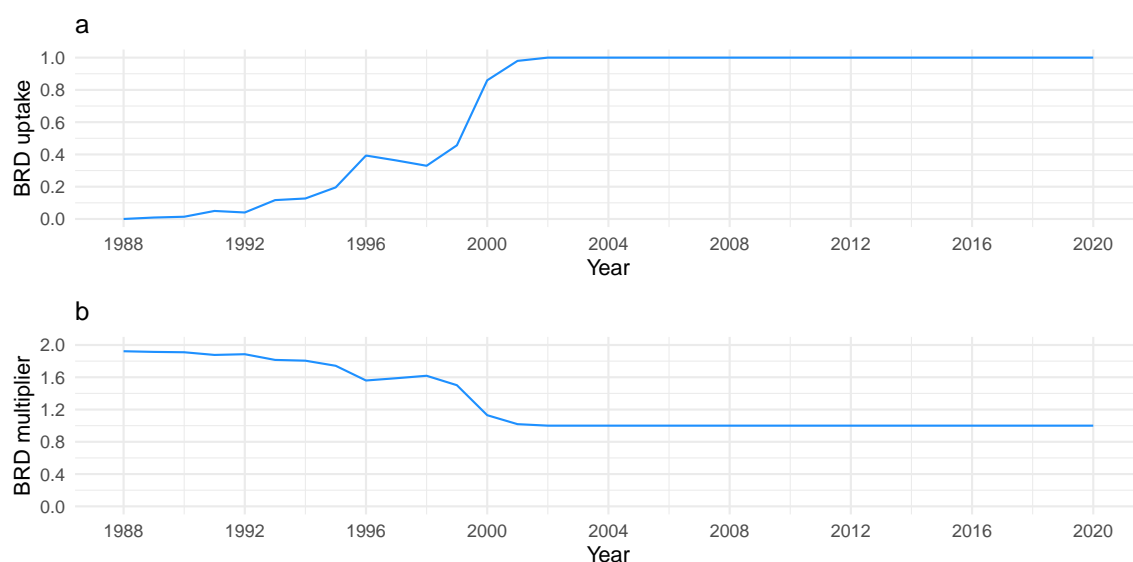


Figure A.1: a) Take up rates of BRD and b) BRD multiplier

Appendix B Model outputs

B.1 Parameter estimates

Model parameters were estimated and parameter labels follow a Stock Synthesis specific naming convention (Table B.1). Parameter estimates for the base case scenario are shown (Table B.2), parameter estimates for additional scenarios were similar. In addition, recruitment deviations were estimated between 1991 and 2020.

Table B.1: Parameter label explanation

Parameter Label	Explanation
SR LN(R0)	logarithm of the number of recruits in 1945
SR BH steep	steepness parameter (h)
CV young	Coefficient of variation in total length at Age 1
CV old	Coefficient of variation in total length at Age 8
LnQ base CommercialQLD	logarithm of the catchability of the commercial QLD fleet
LnQ base CommercialNSW	logarithm of the catchability of the commercial NSW fleet
Size inflection	Fishery selectivity, asymptotic, parameter p_1 - ascending inflection (cm)
Size 95% width	Fishery selectivity, asymptotic, parameter p_2 - ascending width (cm)

Table B.2: Parameter estimates for the base population model where natural mortality is 0.6996 per year

Parameter Label	Estimate	Phase	Min	Max	Initial value	Standard deviation
SR LN(R0)	20.17	1	15	40	30	0.08
SR BH steep	0.36	3	0.21	0.99	0.4	0.02
LnQ base CommercialQLD	-15.68	3	-17	1	-10	0.12
LnQ base CommercialNSW	-15.65	3	-17	1	-10	0.14
Size inflection	14.22	3	0.2	20	0.5	0.18
Size 95% width	1.93	3	0.01	20	10	0.19

B.2 Goodness of fit

B.2.1 Abundance indices

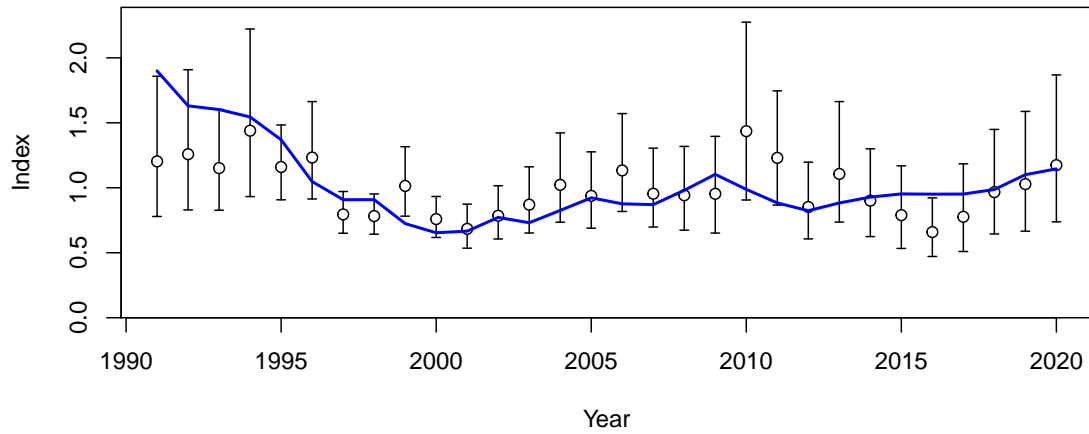


Figure B.1: Model predictions (blue line) to Queensland commercial standardised catch rates (points)—black bars represent the standard error input into the model

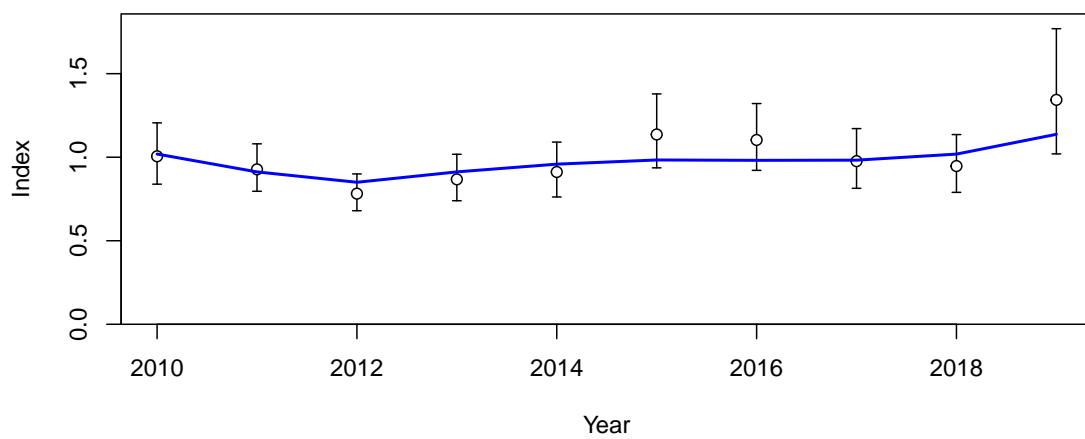


Figure B.2: Model predictions (blue line) to New South Wales commercial standardised catch rates (points)—black bars represent the standard error input into the model

B.2.2 Length compositions

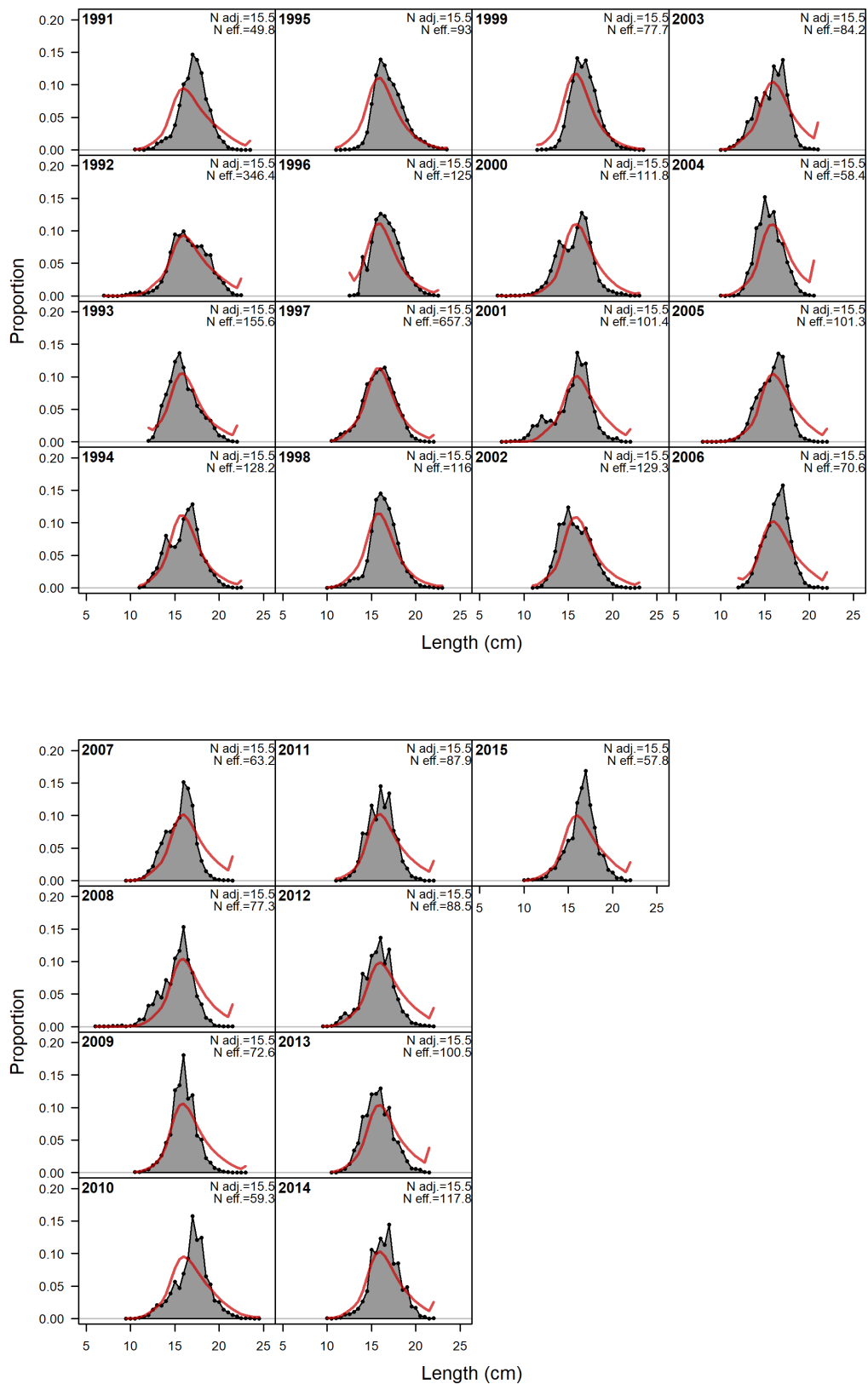


Figure B.3: Fits to length structures for the Queensland commercial fleet Note: 'N adj.' is the input sample size after data-weighting adjustment—'N eff.' is the calculated effective sample size used in the McAllister–Iannell tuning method—New South Wales fits were similar

B.2.3 Age compositions

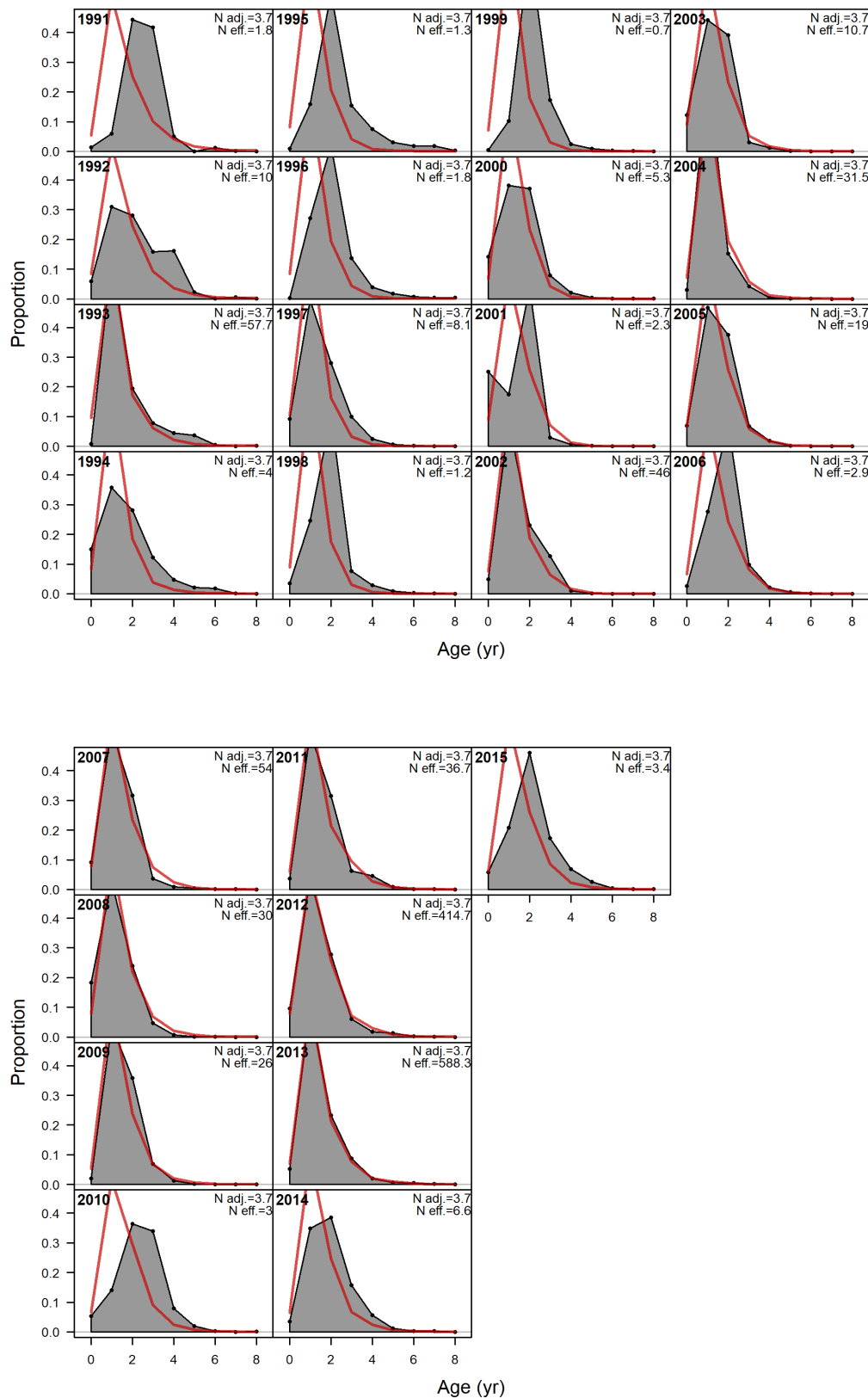


Figure B.4: Fits to age structures for the Queensland commercial fleet Note: 'N adj.' is the input sample size after data-weighting adjustment—'N eff.' is the calculated effective sample size used in the McAllister–Lannell tuning method—New South Wales fits were similar

B.2.4 Selectivity

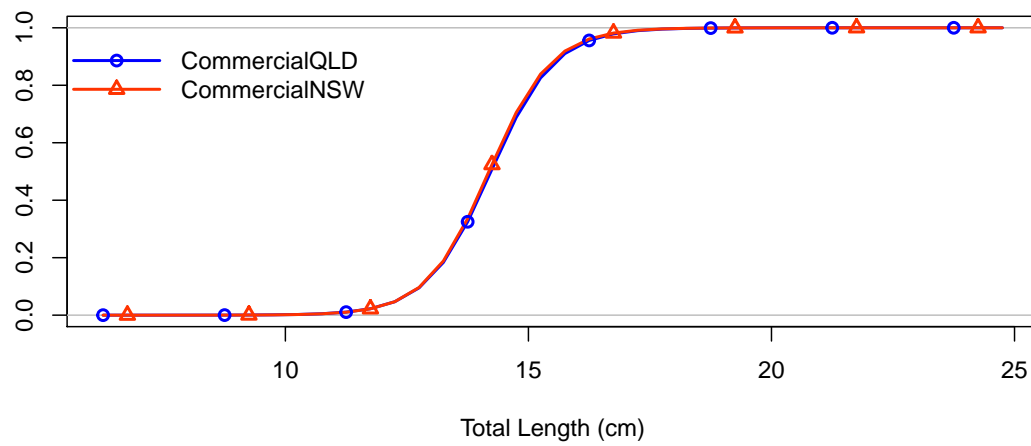


Figure B.5: Model estimated length-based selectivity by fleet in 2020

B.3 Other outputs

B.3.1 Phase plot

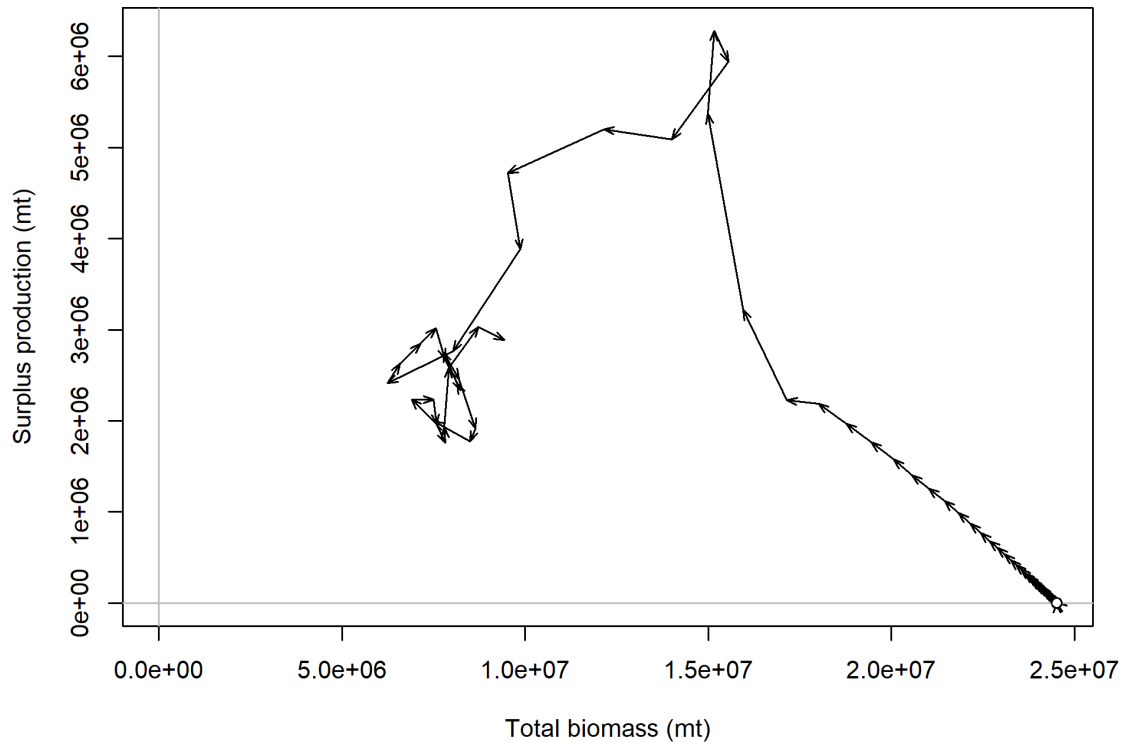


Figure B.6: Phase plot. The horizontal axis is the biomass ratio relative to unfished, and the vertical axis is the fishing mortality relative to fishing mortality at maximum sustainable harvest—the red dashed vertical line is the limit reference point (20% relative biomass), and the blue dashed vertical line is the target reference point (60% relative biomass)

B.3.2 Sensitivity harvest targets

Table B.3: Estimated total harvests and biomass levels of stout whiting to rebuild the stock at the target reference point of 60% unfished spawning biomass, following a 20:60:60 control rule with 0.87 buffer

Year	Harvest (t) $M = 0.55$	Biomass $M = 0.55$	Harvest (t) $M = 0.85$	Biomass $M = 0.85$
2021	1647	0.36	2400	0.48
2022	1897	0.42	2490	0.49
2023	2103	0.47	2568	0.51
2024	2269	0.50	2637	0.53
2025	2398	0.53	2695	0.54
2026	2495	0.55	2746	0.55
2027	2417	0.57	2648	0.56

B.3.3 Catch rate diagnostics

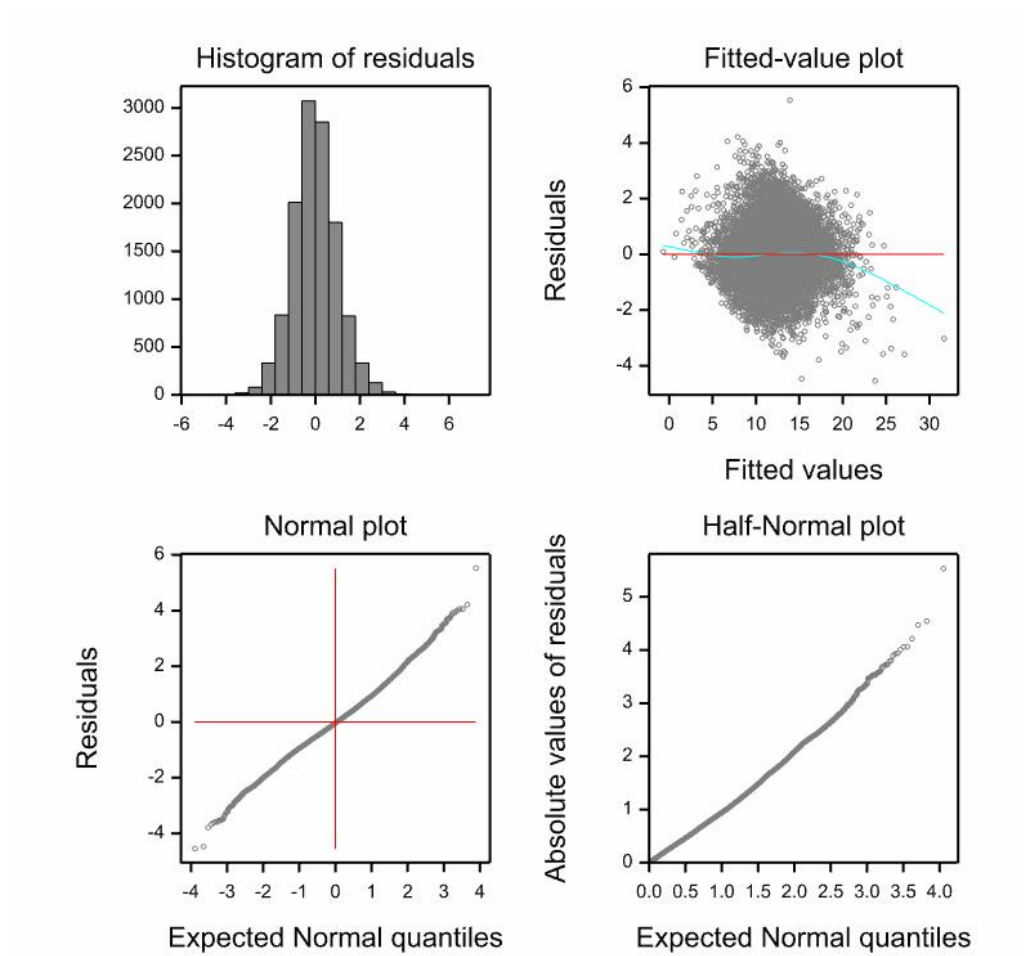


Figure B.7: Residual checking plots for the hierarchical generalized linear model (HGLM) analysis for Queensland catch rates

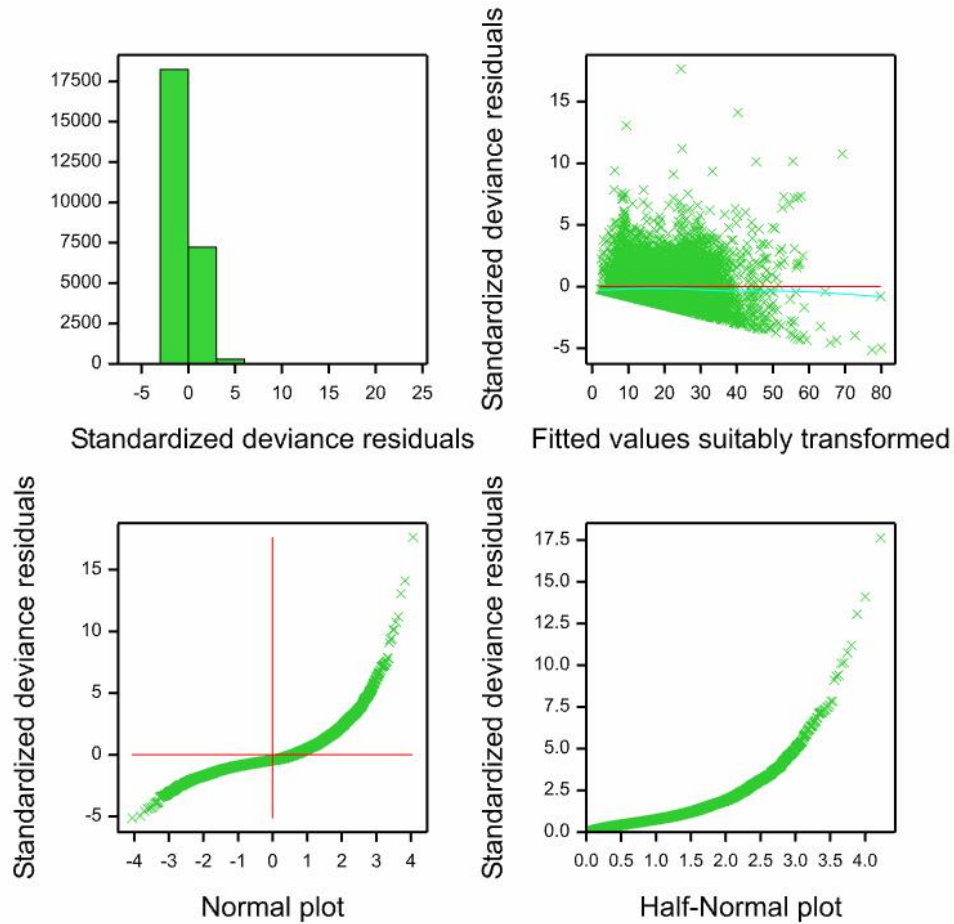


Figure B.8: Residual checking plots for the generalized linear model analysis for New South Wales catch rates

B.3.4 Stout whiting licences

There were six stout whiting licences in Queensland in 1991 (Figure B.9) with once licence leaving the fishery in December 1991.

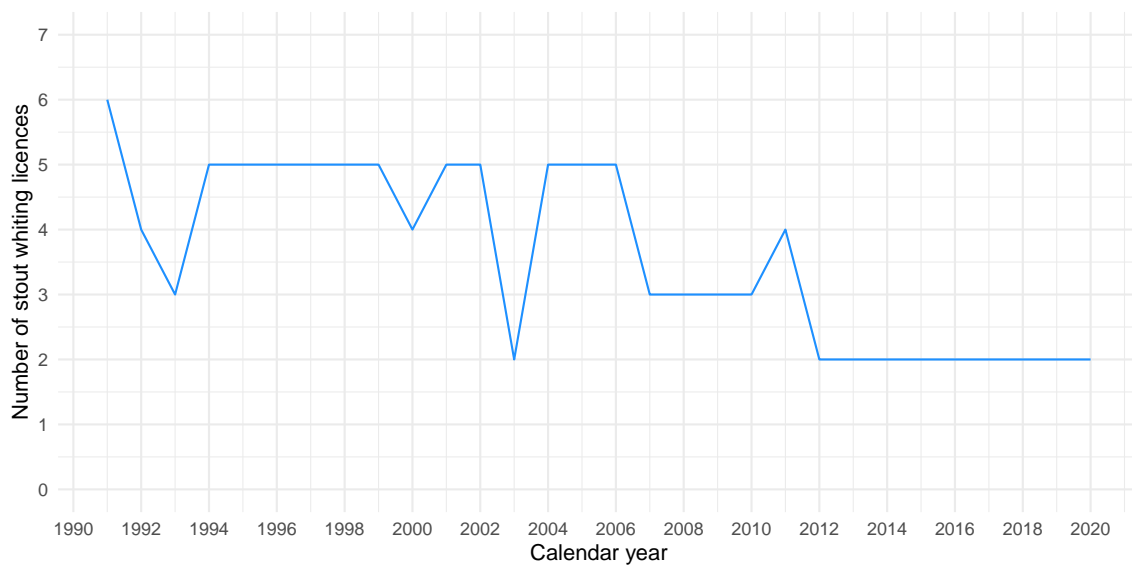


Figure B.9: Number of Queensland licences for the stout whiting fishing sector from January 1991 to June 2020

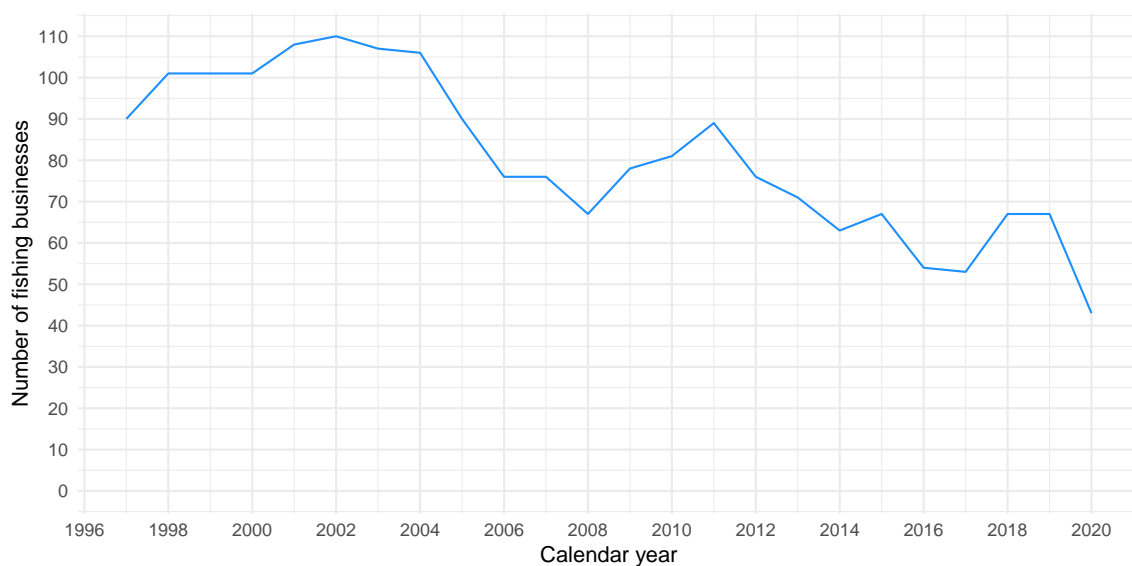


Figure B.10: Number of New South Wales fishing businesses in the prawn trawl fishing sector that reported stout whiting catch from July 1997 to June 2020